Making Things Better: Competing in Manufacturing

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Foreword

U.S. manufacturing is in trouble. That spells trouble for the Nation, because manufacturing provides well-paid jobs, pays for most privately funded research and development, and dominates international trade. In industry after industry, U.S. manufacturers have lost out to competitors who are able to make things better—products with better features and more reliable quality, at lower cost. The key to this better performance is technology, which includes not only new products and advanced manufacturing equipment but also efficient organization of work and effective use of people. Once, U.S. manufacturers led the world in technology. Now, in one field after another-first radios and TV, then automobiles, now semiconductors—Japanese manufacturers are passing us by. Other Asian countries like Korea and Taiwan are coming up fast, and Europe is mounting new challenges.

In a sense, these changes are welcome. Since World War II, U.S. policy has aimed to strengthen the economies of advanced nations and help poorer ones develop, so it should be no surprise that the world is now full of able manufacturers. It was not part of the plan for the United States to fall to second rank, but that is what is happening.

This report considers ways to promote the restoration of American leadership in manufacturing technology. Some of the things that most need doing are up to industry—especially in handling people, from managers to engineers to shopfloor workers, and in forming stable, productive relationships between different segments of an industry complex. Government also has a critical role to play. The first essential is to create an economic environment that supports manufacturing and encourages long-term investment in technology. This means higher national savings rates and a declining Federal deficit. Other less traditional activities (at least for the U.S. Government) also deserve consideration-for example, collaboration with industry on supporting R&D for strategic technologies.

For many years, national security was almost the only acceptable reason for government support of commercial technologies and industrial excellence, but as the Cold War winds down, this reason becomes less compelling. In an era of more secure peace but tougher economic competition, national security is taking on new meanings. To preserve our long tradition of industrial success and rising living standards requires continuing innovation and successful adaptation of existing technology, and that is a task for industry, government, and American citizens.

This report is the second in a series of three in OTA's assessment of Technology, Innovation, and U.S. Trade. The assessment was requested by the Senate Committee on Finance; the Senate Committee on Banking, Housing and Urban Affairs; and the House Committee on Banking, Finance and Urban Affairs. The first report in the series, *Paying the Bill: Manufacturing and America's Trade Deficit,* concluded that the stubbornly high U.S. trade deficits of the 1980s and many other signs pointed to genuine weakness in American manufacturing and lags in technology, compared to our best competitors. This report looks for some of the reasons for the weakness, and suggests policies aimed specifically at repairing it. The last report will examine the trade and industrial policies of Japan, other East Asian countries, and Europe; and their possible relevance to the competitive position of the United States.

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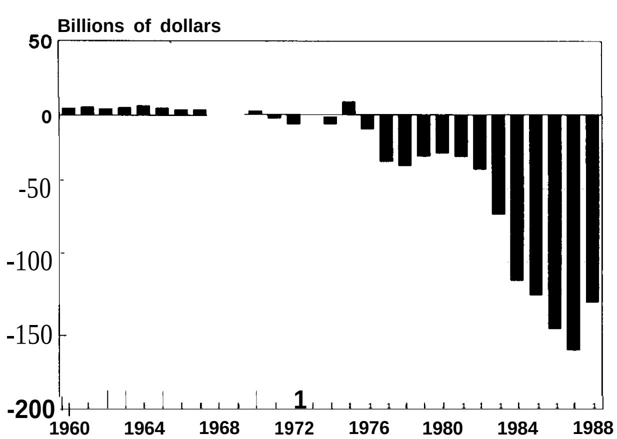
Chapter 1
Summary

American manufacturing has never been in more trouble than it is now. Its biggest challenge is from Japan, where, more than in any other nation, well-designed products are manufactured with great reliability, while costs are rigorously controlled. Other nations, developed and developing, are rising to the Japanese challenge in creative ways. The important difference is that many of those nations are responding *as nations,* with the support and participation of government. While some American companies and institutions have redoubled efforts to improve manufacturing, the government is dozing at the switch. Certainly, there are many problems that manufacturers must solve themselves. But some of the problems are generated by the American people and government. As a nation, we owe it to ourselves to help with their solution.

Symptoms of America's problems are clearly visible: the merchandise trade deficit remains stubbornly high, despite significant downward adjustment of the dollar against major currencies (figure l-l). Productivity growth is sluggish compared with that of many other advanced and developing nations, including our ablest competitors (figure 1-2). U.S. manufacturers are increasingly dependent on foreign producers for a wide range of machinery and tools of production. Even the microelectronics industry, once the standard bearer for American competence and inventiveness, is losing sales and market share to Japanese, Korean, and Taiwanese producers.

Figure 1-1--Merchandise Trade Balance



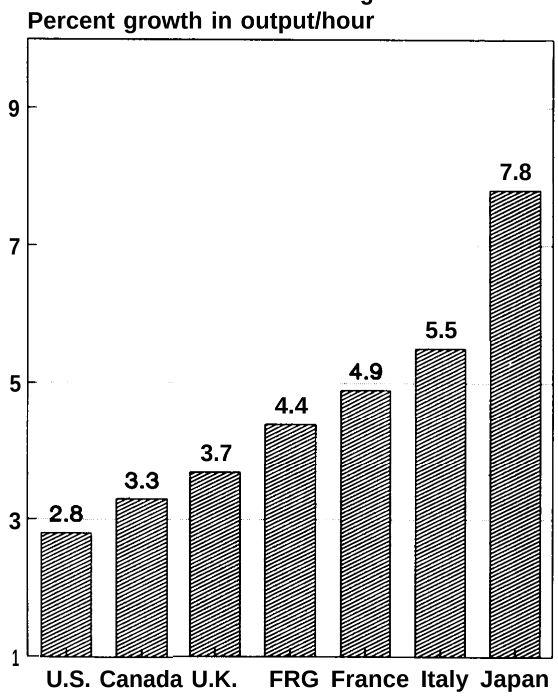
SOURCE: U.S. Department of Commerce, Bureau of Economic Analysis, *Business Conditions Digest, September 1939* (Washington, DC: U.S. Government Printing Office, September 1989), table 822.

The weaknesses in U.S. manufacturing technology must be cured if the Nation is to enjoy rising living standards together with a strong, stable position in international trade. Most of the U.S. trade deficit is in manufactured goods (figure 1-3). The most constructive way to right the deficit is to manufacture products that the world will buy because the products are well-made and reasonably priced (not just because a low dollar makes them cheap). More fundamentally, manufacturing is valuable to the Nation as a direct source of productive, well-paid jobs and the indirect source of many better-than-average jobs in the service sector (table l-l). Manufacturing also supports most of this country's commercial research and development.[1]

There is no single solution, but all the signs point in one direction: U.S. manufacturing technology must improve—in everything from product design to manufacturing process development and refinement. For industrial nations, technology is the key to competitive success. Nations that rely on low wages to sell their goods in the world market are, by definition, poor, whereas superior technology raises productivity and thus supports rising standards of living. Moreover, technology is a steady, predictable source of advantage, while others may shift with political currents. For example, a nation's fiscal and monetary policies affect the

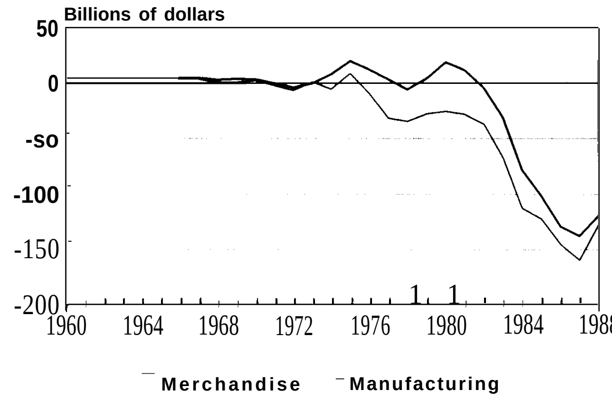
[1]For more detailed discussion of the place of manufacturing in international trade and the national economy, see Office of Technology Assessment, *Paying the Bill: Manufacturing and Americans Trade Deficit,* OTA-ITE-390 (Springfield, VA: National Technical Information Service, 1988).

Figure 1-2—Average Annual Productivity Growth in Manufacturing



SOURCE: U.S. Department of Labor, Bureau of Labor Statistics,"International Comparisons of Manufacturing Productivity and Labor Trends, 1986," June 1989, table 1.

Figure l-3-Merchandise and Manufacturing Trade Balances, 1960-88



SOURCES: U.S. Department of Commerce, Bureau of Economic Analysis, *Business Conditions* Digest, *September 1989* (Washington, DC: U.S. Government Printing Office, September 1969), table 622; U.S. Department of Commerce, International Trade Administration, Office of Trade and Information Analysis, unpublished data, 1989; and President of the United States and the Council of Economic Advisers, *Economic Report of the President* (Washington, DC: U.S. Government Printing Office, January 1987), table B-102.

value of its currency, which in turn affects the salability of its manufactured goods in the world market. But macroeconomic policies are changeable, and are far beyond the control of private fins.

Americans are used to thinking of their nation as leading the world in technology—with the select company perhaps of a few other developed countries or a few foreign industries. But the realization has dawned that we are no longer at the forefront.[2] Several major U.S. industries have not only fallen behind in technology, but will be hard put to catch up even if they adopt a whole catalog of changes needed to reverse the slide. Not all American industries are lagging, but trends in many sectors, from computers to aircraft, indicate that our ablest competitors can now or soon will match our technology, and are accelerating faster.

Is this a problem? We have long accepted (in principle, if not in fact) that our technological lead across a wide range of industries was fated to narrow or disappear as developed countries recovered from war damage and poorer countries advanced. But we did not expect the gap to close so rapidly, and we certainly never expected to fall behind.

The toughest challenge is coming from the Far East. At the close of the 1980s, Japan has emerged as the world's premier industrial competitor. The United States is still the richest of nations, with gross domestic product per capita considerably higher than most others (only Canada is close; see figure 1-4). Several European countries are strong performers in one or another manufacturing sector or product—especially Germany, which excels in metalworking and machinery, and consistently runs large trade surpluses. But Japan's record is unique. It has led all major industrial countries in productivity growth for decades—not just in the early postwar years when it was rising from the ashes, but also right through the 1970s and

[2]For aggregate indicators of America's relative technological performance, ibid., pp. 26-35.

Table I-I—Work Force Involved in Manufacturing and Average Full-Time Equivalent Compensation, 1984

	Wage and salary workers involved in manufacturing	Percent of sector employment involved in manufacturing	Average annual full-time equivalent compensation (thousands of dollars)
Agriculture	792	50.4%	$11.3
Mining	443	45.5	37.0
Construction	575	13.3	26.8
Manufacturing	19,396	100.0	28.7
All public and private services	6,492	9.4	246
Ail private services	6,343	11.9	24,4
Wholesale trade	1,501	26.3	27.6
Transportation and warehousing	704	24.2	30.3
Business services	1,276	22.8	24.7
Radio and TV broadcasting	50	21,8	29.6
Electric, gas, water and sanitary services	171	21.4	37.5
Communications, except radio and television	129	11.6	39.7
Automobile repair and services	79	11.6	17.8
Retail, except eating and drinking	1,176	10.3	17.1
Finance and insurance	413	9.0	27.4
Hotels, personal and repair services (exe. auto)	207	8.5	15.7
Eating and drinking places	428	7.9	11,0
Real estate and rental*	72	6.7	21.1
Amusements	46	4,5	19.9
Health, educ. & social sew. and nonprofit org.....,	89	0.9	20.2
Government	149	0.9	31.1
Total	27,697	29.0%	$27.4

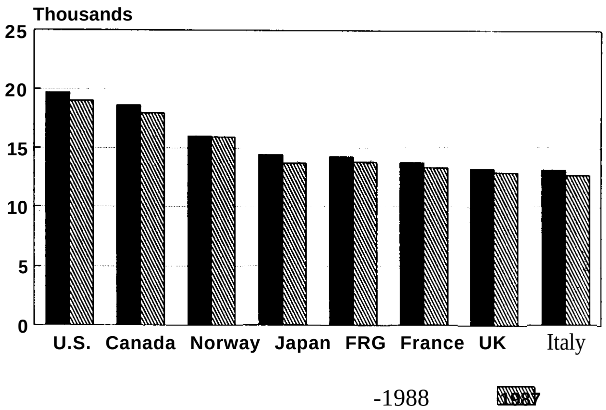
SOURCE: Workers involved in manufacturing data is derived from OTA Input-Output Model (1980 technical coefficients, 1984 estimated demand, 1984 BLS employment, adjusted for capital flows, imports andduties). Compensation data derived from Bureau of Economic Analysis, National Income and Product Accounts, electronic data, mapped to input-output industry classifications.

1980s, despite the oil shocks and two periods of a steeply rising yen. Alone among advanced industrial countries, Japan managed in the 1980s to combine great productivity growth in manufacturing with rising manufacturing employment, rising wages and benefits, and greatly rising output.

These singular achievements suggest some systematic advantages in Japan that are well worth examining. There are of course elements of superiority in other countries too (including the United States) and things to be learned from them. But Japan's sustained improvement in productivity and its pre-eminence in several industries that were once nearly an American preserve (e.g., computers, semiconductors) make Japanese manufacturing a subject of special interest. Thus this assessment on the contribution technology makes to competitiveness in manufacturing concentrates quite heavily—though not exclusively--on Japan.

The Japanese accomplishment rests to a great extent on technology. Broadly defined, manufacturing technology covers not only the generation of new products but also know-how in using equipment, organizing work, and managing people to make the products. Where U.S. firms have fallen down in recent years is in the manufacturing process. The American system, including our great universities as well as industrial labs, still excels at making technical discoveries and inventing new products. But foreign companies (especially Japanese companies) have repeatedly beaten U.S. firms in getting new, improved versions of a great many products to market while keeping costs competitive and quality high.

Figure 14-GDP Per Capita in 1988 U.S. Dollars
(Purchasing Pourer Parity Exchange Rates)



SOURCE: U.S. Department of Labor, Bureau of Labor Statistics, Office of Productivity and Technology, unpublished data, August 1989.

Over the past decade or so, we have learned much about the sources of the Japanese manufacturing superiority. We have become familiar with features such as *kaizen,* or continual improvement in every detail of manufacturing; the training of workers to participate in */wizen,* learn multiple skills, and work in teams; and ***kanban, the*** just-in-time delivery system for parts that depends on reliable high quality and reveals failures to achieve it. These features are all part of the "lean" production system that is practiced by the leading Japanese manufacturers and is widely credited with keeping costs low and quality high. The "buffered" system, common in U.S. plants, depends on having large stocks of parts and work in progress, so that faulty items can be replaced, and sizable repair areas for fining up defects in the finished product.[3] The lean system, by contrast, is designed to expose problems while the work is in process, solve the problems, and from there on do it right the first time. If this report gives only passing attention to some of these aspects of Japanese manufacturing, that is not because they lack importance, but because they are very well-known.

Greater investment in advanced equipment is another advantage of leading Japanese industries. From 1976 through 1987, Japanese investment in machinery and equipment consistently ran from 14.9 to 20.6 percent of GNP; in America, it ranged from 7.5 to 9.0 percent of GNP[4] (figure 1-5). Japanese capital investment in the late 1980s was especially high, posting double-digit increases in both 1988 and 1989. In manufacturing, the rate of increase was even greater--over 25 percent for both years. An important reason for these whopping investment increases was a shift in production to higher value added goods.[5] Capital investment in American manufacturing rose only 9 percent from 1988 to 1989 (less in real terms).

It is not simply advanced hardware that gives Japanese manufacturers the edge, however. Their genius lies at least as much in the employment of people in relation to the hardware. This effective use of people is also a factor in the Japanese ability to shorten the product development cycle—to repeatedly incorporate state-of-the-art improvements in their products and bring them to market quickly. For example, it takes Japanese auto companies about 3 1/2 years to get a new model from design to full-scale production, compared to over 5 years for American and European auto makers.[6] A key difference is the Japanese emphasis on simultaneous rather than sequential engineering. The people doing research, development and design of the new model are in constant communication with the people responsible for manufacture. Other factors are involved too, such as the reliance of the major manufacturers on a trusted group of suppliers to do part of the product development work. The result is a headstart over

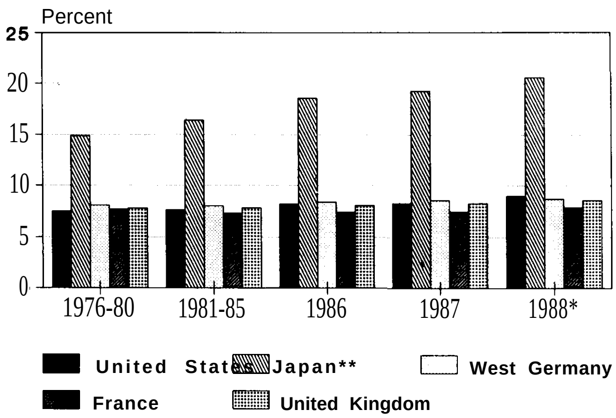
[3] These terms were coined by John F. Krafcik, "A New Diet for U.S. Manufacturing,' *Technology Review,* Jan. 28, 1989.

[4] International Monetary Fund, *World Economic Outlook,* April 1989. The Japanese figures exclude public investment, while those for the United States do not.

[5] The Japan Development Bank, "The Japan Development Bank Reports on Capital Spending: Survey for Fiscal Year 1988 to 1990," Economic and Industrial Research Department, September 1989.

[6] Kim B. Clark and Takahiro Fujimoto, "Overlapping Problem Solving in Product Development" working paper 87-048, Harvard Business School, revised April 1988.

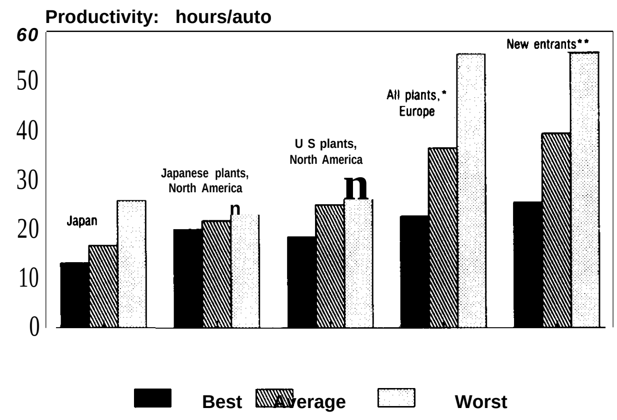
Figure 1-5-Fixed investment in Machinery and Equipment as a Percentage of GNP/GDP



•January to June
** Figures for Japan exclude public investment.

SOURCE: International Monetary Fund (IMF), *World Economic Outlook* (Washington, DC: April 1989), table 17.

Figure 1-6-Productivity Performance, World Auto Manufacturers



•Includes foreign owned.
•* Includes East Asia, Mexico, and Brazil.

SOURCE: John F. Krafcik and John Paul MacDuffie, "Explaining High Performance Manufacturing: The International Automotive Assembly Plant Study," paper prepared for the International Motor Vehicles Program International Policy Forum, May 1989.

slower competitors in responding to consumer preferences and, perhaps even more important, in incorporating the latest technologies.

Some American managers are now adopting Japanese-style approaches, or versions of them, to turn out better goods at lower cost. For example, in the early 1980s, it took twice as many hours to assemble a standard car in an average American auto plant as in the average Japanese plant. By 1988, U.S. assembly plants had improved enough that the Japanese advantage was down from 100 percent to about 50 percent (25.1 hours for assembly in the average U.S.-owned and managed plant v. 16.8 hours in the Japanese). The best Japanese plant had an advantage of 5.4 hours over the best American plant[7] (figure 1-6).

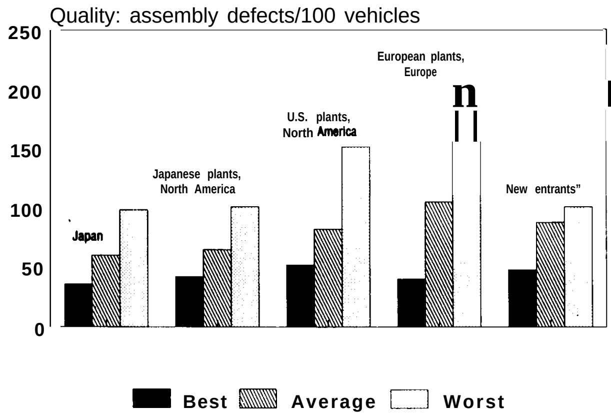
In quite a few other industries (e.g., textiles and steel), well-managed U.S. firms have shown that they are able to turn some of the Japanese-style approaches to good account. But that is no reason for complacency. For one thing, the target is moving. Faced with the high yen, which raises the prices of goods they export, the Japanese Government and Japanese manufacturers redoubled their own efforts to improve technology and competitiveness. For example, the best Japanese plant shaved assembly time for a standard model car from 16 to 13.2 hours in just one year, 1987 to 1988, and the average plant improved from 19.1 hours to 16.8.[8] The Japanese were also holding onto a lead in better quality. In 1988, the average Japanese assembly plant was turning out cars with less than three-quarters of the defects of cars produced in American plants. U.S. plants stacked up very well against the Europeans, however, as shown in figures 1-6 and 1-7.

The reasons for Japanese success are broad and complex. Public as well as private actions, and the interrelation between them, are very much involved. The issues selected for analysis in this assessment include both, and may be grouped into a few broad areas: 1) the cost and availability of capital, and its influence on business decisions to invest for the long pull in product and process improvements; 2) the use of

[7]John F. Krafcik and John Paul Mac Duffie, ' 'Explaining High performance Manufacturing: The International Automotive Assembly Plant Study," working paper of the International Motor Vehicles program of the Massachusetts Institute of Technology, May 1989.

'Ibid., p. 5.

Figure 1-7--Quallty Performance, World Auto Manufacturers



•Includes East Asia, Mexico, and Brazil
NOTE: Data are derived from 1988 J.D. Powers International Quality Survey and corporate data.

SOURCE: John F. Krafcik and John Paul MacDuffie, "Explaining High Performance Manufacturing: The International Automotive Assembly Plant Study," paper prepared for the International Motor Vehicles Program International Policy Forum, May 1989.

human resources to contribute to manufacturing excellence, with special emphasis on engineers; 3) relations between supplier and customer firms within an industry complex, in particular the benefits of close, cooperative links; 4) ways to diffuse new technologies from outside sources to private companies, and especially to smaller manufacturers; and 5) existing government programs-Federal, State, regional and local—that help (or in some cases hinder) U.S. manufacturing firms in using technology to improve their competitive performance.

Lessons from the successes of other countries are not always easy to apply. Some elements in the Japanese system may be quite adaptable to U.S. companies that are enterprising enough to try them-for example, close relations between different segments of an industry complex (e.g., chemical companies that make textile fibers, textile producers, apparel makers, designers, and retailers) in which suppliers are attuned and responsive to the needs of their customer firms, and purchasers are willing to form stable, cooperative relations with their suppliers. Other practices and policies of foreign nations would be much harder to translate into American terms-for example, the century-old system of vocational education that trains half the young people of West Germany in good work habits and a variety of skills. And some policies of other nations are quite foreign to our traditions and outlook-for example, centralized direction of trade and industrial policy as practiced in Korea (until recently, when controls have loosened somewhat).

One way or another, however, the United States must regain excellence in the manufacturing process. That is key to raising income for the Nation. No longer can U.S. industries count on profiting from new inventions for years before competitors begin to produce them. Many technical inventions cannot be protected from skillful imitators-and the world is now full of manufacturers who can quickly and ably produce things that were invented elsewhere (just as U.S. manufacturers themselves have often done with foreign inventions). Over the long run, a country and its citizens cannot control or profit from what they cannot produce competently.

Restoring or creating excellence is no easy task. U.S. manufacturers who once were the masters of mass-production grew complacent in the years of American domination. Many still cling to wasteful production systems that take a narrow view of cost reduction, and do it at the expense of reliability, flexibility, and customer service. Many smaller manufacturers are far behind the times technologically. Federal technology policy is still aimed much more at research and the generation of new inventions than at quickly diffusing new technologies (whatever their source) and putting them into practice. Some government policies run counter to manufacturers' efforts to improve their performance, although that is not their intention. Most important is the government's inability to eliminate the budget deficit, which increases pressure to raise interest rates and the value of the dollar, and directly diminishes manufacturers' ability to sustain long-term, risky investments. The Federal Government, along with many State and local governments, has initiated some new programs to help manufacturers improve competitiveness and technology, but these are mod-

est at best. The dampening effects of macroeconomic and foreign policies can easily overwhelm them.

With will and effort, a nation's industries can change. Forty years ago, Japan was a poor nation, backward in manufacturing technology, lacking engineers and scientists, relying mostly on low labor costs to make products attractive enough for export. Between that Japan and the Japan we know today are years of heavy investment in people, technology, and machinery, and a great deal of sacrifice on the part of consumers. The United States today is in a far stronger position than Japan was then but, ironically, this may make it harder to undertake the sacrifices and changes needed to rebuild our competitiveness. We are still a wealthy nation, and there is no widespread feeling that we are in or approaching a crisis. Under such circumstances, it would take extraordinary leadership to summon the energies to make significant changes. One hopeful sign is that the nations of the European Community—also wealthy and with no apparent crisis—have pulled together to create a new economic order, with the Single Market Act.

The European Community's efforts to harmonize internal markets beginning in 1992 have several things in common with the measures Japan took to industrialize two decades ago. They also have much in common with measures the United States needs to consider to improve our competitive performance. Broadly speaking, they are measures to promote investment in people, technology, and equipment; to disseminate information and know-how; and to encourage cooperative efforts to solve common problems.

INVESTMENT

Investments in technology require patience. Researchers, inventors, and designers often must wait years—sometimes decades—for their efforts to pay off. Although investments in equipment are more predictable and less risky, even these may not break even for years.

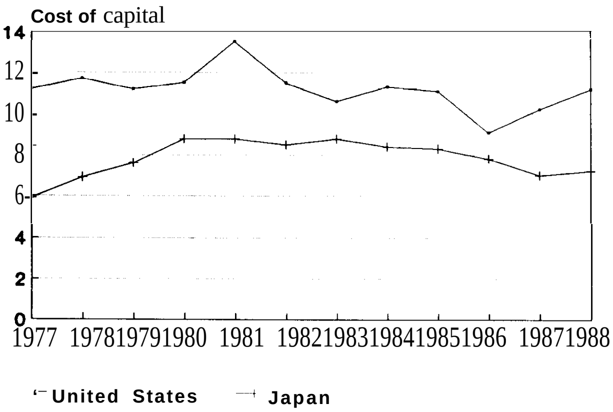
America's financial climate is not conducive to long-term investments in technology and equipment, compared with Japan, Germany, and the most rapidly developing Asian nations. Several things contribute to this relatively unfriendly environment. High U.S. capital costs shorten the time horizons of investors, so do the pressures exerted on companies by the stock market, particularly by institutional investors and takeover specialists. In sum, both government policies and business practices reinforce an excessive concern with short-term profit in America. If these conditions persist, it will be increasingly difficult to keep up with technological advances made elsewhere.

U.S. capital costs have been and remain high compared with those in Japan, the nation that provides the greatest contrast with U.S. short-term thinking. There is some disagreement over just how large (or small) the differences are, but most recent studies estimate significantly higher capital costs in the United States[9] (figures 1-8, 1-9, and 1-10). On the high side, the estimates range up to 13 percentage points difference, while the difference at the low end is on the order of 1 or 2 percentage points. Even relatively modest differences of a few percentage points in capital costs can be a significant disadvantage in making investments that take many years to pay off.

U.S. capital costs are high for many reasons. Interest rates rose in the 1980s and remain high principally because of the enormous pressure of the budget deficit, which is a large drain on savings, and the fall in other savings rates. But there is a great deal more to capital costs than interest rates. The price a firm pays for capital is also a function of its relationships with creditors and equity holders, and the taxes it pays. During Japan's high growth period, which lasted until 1973-74, heavy reliance on debt financing from main banks kept capital costs down for Japanese

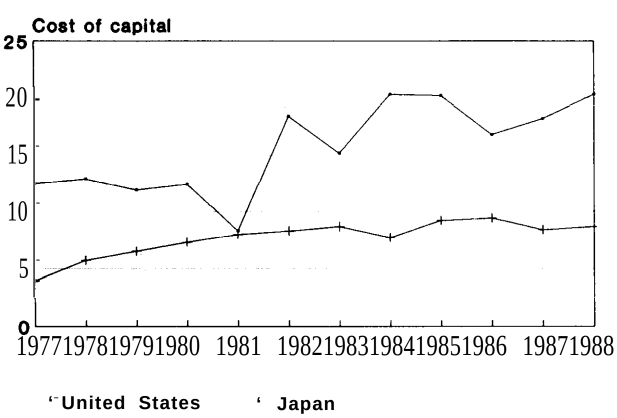
[9] Michael L. Dertouzos, Richard K. Lester, and Robert M. SoloW, Made *in America: Regaining the Productive Edge* (Cambridge, MA: The MIT Press, 1989).

Figure 1-8--Cost of Capital for Equipment and Machinery With %)-Year Physical Life



SOURCE: Robert N. McCauley and Steven A. Zimmer, "Explaining International Differences in the Cost of Capital," *Federal Reserve Bank of New York Quarterly Review*, Summer 1969, table 2.

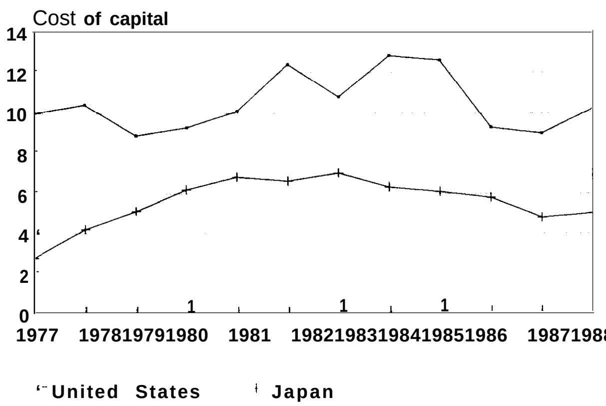
Figure I-9-Cost of Capital for R&D Project With 10-Year Payoff Lag



SOURCE: Robert N. McCauley and Steven A. Zimmer, "Explaining International Differences in the Cost of Capital," *Federal Reserve Bank of New York Quarterly Review*, Summer 1989, table 2.

manufacturing firms (particularly in favored industries). A variety of Japanese Government policies encouraged the banks to lend heavily at low rates to large corporations. These policies included direct government lending through the Japan Development Bank (which is a signal to private banks), administrative guidance from the Ministry of Finance, and close regulation of

Figure I-l O-Cost of Capital for Factory With 40-Year Physical Life



SOURCE: Robert N. McCauley and Steven A. Zimmer, "Explaining International Differences in the Cost of Capital," *Federal Reserve Bank of New York Quarterly Review*, Summer 1989, table 2.

every aspect of banking and finance, including the disposition of household savings.

Today, Japan has enormous capital reserves, and most major corporations finance all their investment with retained earnings and depreciation. Moreover, Japan is deregulating its financial markets, and large Japanese companies are getting more of their external capital in foreign markets. Most estimates of U.S. and Japanese capital costs still show American firms at a substantial disadvantage-one study, for instance, reports U.S. cost of capital at 20.3 percent, compared with 8.7 percent in Japan.[10] But even if nominal costs were the same, differences in the financial environments in the two countries would still favor Japanese firms. Most of the stock of large Japanese corporations is held by other corporations, often in the same *keiretsu* (industry group), who agree to hold the stock for long periods with few demands in return. This system, known variously as cross shareholding, mutual shareholding, or stable shareholding, is in marked contrast with U.S. practice. Here, shareholders must be given far more attention; corporations pay larger dividends, and corporate managers are under heavy

[10] Robert N. McCauley and Steven A. Zimmer, "Explaining International Differences in the Cost of Capital,' *Federal Reserve Bank of New York Quarterly Review*, *summer 1989*, pp. 7-28. These figures apply to investments in research and development. Other investments, such as equipment and machinery and factories, are also shown to be more expensive in America than in Japan and West Germany.

pressure to show a profit each quarter. In the 1980s, new financial instruments have made it much easier for outsiders to mount takeover bids, and managers in U.S. companies feel that they must show profits or become vulnerable to takeover attempts. American managers' increasing preoccupation with the short-term bottom line in the 1980s is in part due to that vulnerability.

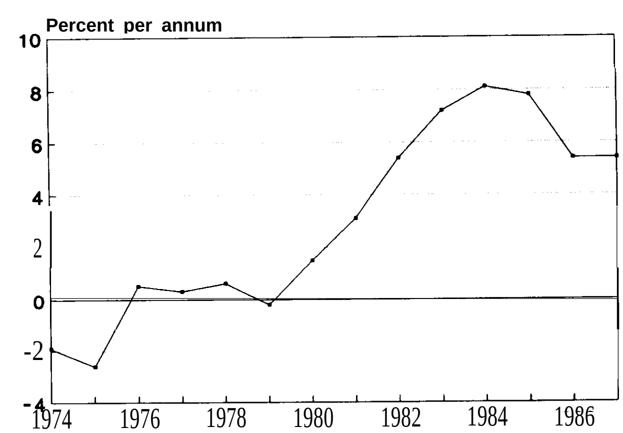
Several other factors tend to reinforce short-term bias in America. None by itself is conclusively important, but together they have a considerable effect. Company size and structure may account for some of the short term focus of the semiconductor industry, in particular. The leading Japanese semiconductor producers are large, integrated, stable companies making a variety of products, from semiconductors to computers and consumer goods. The U.S. industry has a few large, integrated producers, making chips mostly for their own use, but the merchant firms that sell semiconductors to systems makers are mostly smaller, entrepreneurial companies. Such companies have been highly innovative, but also highly unstable. Personnel turnover (especially defections to start new firms) is high, as are rates of entry and exit. Their relatively small size, instability, and irregular cash flow make it especially hard for them to raise the large amounts of capital required for semiconductor production. These factors exaggerate the short-term focus that is endemic in U.S. financial markets.[11]

Government policies that increase uncertainty also aggravate the problem. For example, in the 1980s, American business managers were faced with a very high dollar, which made it harder to sell goods abroad and to compete against foreign goods at home. The dollar finally began falling in 1985. But throughout the high dollar period of the early 1980s, the U.S. Government made no provision for firms working under that disadvantage. In contrast, the Japanese Government put in place special loan and loan guarantee programs to help Japanese firms cope with ***endaka*** (high yen) after the international accords that brought the dollar down in 1985.

The single most important step the government could take to improve the financial environment is to greatly reduce the Federal budget deficit, and eventually eliminate it. That would help to lower interest rates and allow the dollar to find a level that more accurately reflects the competitiveness of American industry (Figure 1-11 shows real long-term interest rates in the 1970s and 1980s.) It would also be a powerful signal to the business community that government could be relied on to provide some stability.

None of this means that American manufacturing is entirely a victim of circumstances beyond its control. U.S. companies are hobbled, but not crippled, by a financial environment that undervalues long-term investment. Some of the myopia of U.S. firms could be overcome through the will of top management. Against the general background of short-term decisionmaking, a few firms standout as long-term investors. Many of these firms have done well. But the power of finance and accounting in American corporations has lifted financial specialists to

Figure 1-1 l—Real Long-Term Interest Rates



SOURCE: Organization for Economic Cooperation and Development (OECD), *Historical Statistics* 1960- 1967 (Paris, France: OECD, 1989), table 10.10.

[11]Dertouzos, et al., 1989, op. cit.

many top decisionmaking spots, and their biases could be difficult to overcome, especially if the rewards for managing for the short-term bottom line do not start to dwindle.

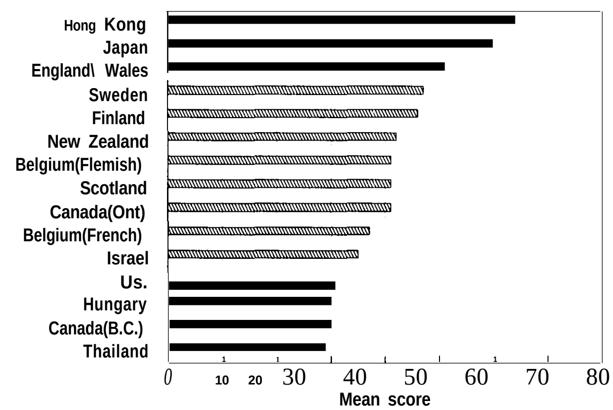
In the discussion so far, investment in technology has been defined as investment in capital equipment, research, and development. The United States also needs well-educated and trained people to make the best use of sophisticated technology. Currently, the investments we make in human resources have disappointing results.

Success in manufacturing depends on the competence and inventiveness of people at all levels. Increasingly, workers from the production line to the executive suite must be comfortable with advanced technology. Production workers are responsible for implementing statistical process control procedures; designers, line managers, and workers must interact frequently and productively; and everyone must assume broader responsibility for making high-quality products effectively. The skills demanded for these tasks are those of analysis and problem-solving. The days when most factory workers used their hands more than their heads are disappearing.

American workers are poorly equipped to cope with these changes, in part because our public schools do not educate many of our children adequately, and in part because firms have been slow to adopt production systems that demand higher order skills, and to train workers to use them. Firms, in turn, are often reluctant to invest heavily in training for fear that they will not be able to recoup their investments.

U.S. educational deficiencies are great in science and mathematics. In the mid-1980s, American junior high school students ranked 10th in arithmetic, 12th in algebra, and 16th in geometry in tests of mathematics competence in 20 countries. In a another comparison of students in 14 nations, American 12th graders ranked 12th in geometry and 13th in advanced algebra (figures 1-12 and 1-13). In the 1960s, American students performed as well as students anywhere in the world. Further evidence of deterioration is the decline in Scholastic Aptitude Test scores over the last quarter of a century.

Figure I-12—Twelfth Grade Achievement Scores in Geometry



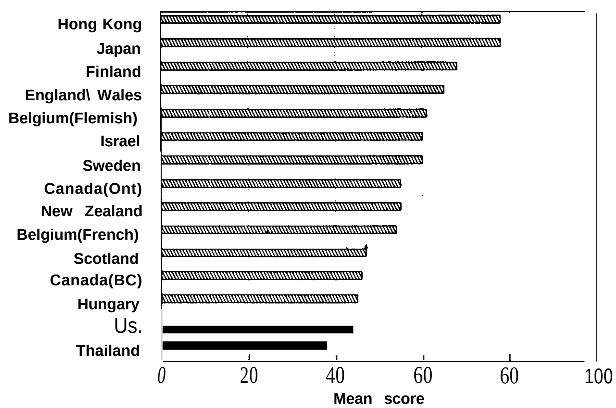
SOURCE: International Association for the Evaluation of Educational Achievement, *The Underachieving Curriculum: Assessing U.S. School Mathematics From an International Perspective* (Champaign, IL: Stipes Publishing Co., 1987).

Workers who cannot cope with mathematics or problem-solving are a liability in advanced manufacturing. For example, Motorola determined that workers in its Factories of the Future needed math skills equivalent to seventh grade proficiency to get by. Even this modest requirement has obliged Motorola to invest tens of millions of dollars in training.

Not only is our general public education inadequate, our vocational education system falls far short of the standards set by other countries. It certainly does not match the apprenticeship training taken by more than half the young people of West Germany. This system gets much of the credit for the broad diffusion of technical competence throughout German manufacturing.

While there are small indications of improvement—a recent turnup in SAT scores, for example-there is need for a great deal more. The fact that American students are behind those

Figure I-13-Twelfth Grade Achievement Scores in Advanced Algebra



SOURCE: International Association for the Evaluation of Educational Achievement, *The Underachieving Curriculum: Assessing U.S. School Mathematics From an International Perspective* (Champaign, IL: Stipes Publishing Co., 1987).

of other advanced nations—and of several developing nations as well—makes it harder for the United States to keep up in manufacturing. Another worrisome trend is demographic. In the past, most engineers and scientists were white males; they now comprise a shrinking portion of the population of school-age children. Minorities and women have historically performed much less well than white males in math and science, for reasons that are only partly understood. To avoid a future scarcity of technologists, the Nation must devote particular efforts to improving math and science proficiencies—of students of both sexes and all races—all the way from grammar school to employer-provided training.

Do we need to invest more money? It is a widely held belief that the United States invests more in educating its children than other nations, both per capita and as a share of gross domestic product.[12] This is clearly true only if post-secondary education is included. A recent study that separated out education past high school found that U.S. public and private spending on schooling from kindergarten through 12th grade, as a share of GDP, is lower than in most industrialized countries-tied for 12th among 16 (figure 1-14). In spending per student in grades K-12, the United States ranks higher—5th of the 16 (figure 1-15).[13] The United States has some special educational problems: our population is much more diverse in culture and language than that of most of our competitors. It could well take heavier investments in human resources to solve our unique problems.

PROMOTING COOPERATION

Partly because of American traditions—the emphasis on individual initiative, for example—and partly because of public policies that limit cooperation, U.S. firms tend to be isolated from customers, suppliers, and competitors compared with Japanese and many European firms. Japanese firms, in particular, are knitted into a network of mutual obligation and cooperation. This is not to say they don't compete; competition is fierce, but is often greater in product quality and features than in price.[14] The bonds of cooperation and obligation, together with relatively limited price competition in the Japanese market, provide Japanese firms with two advantages: access to a wider array of information and support than they would have alone, and enough stability to encourage investment in equipment, knowledge, and people.

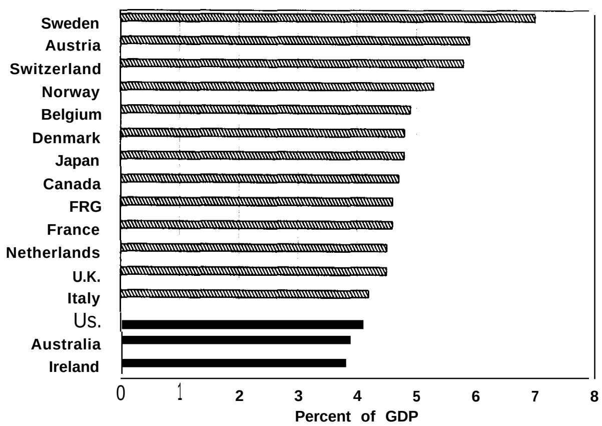
U.S. companies, on the whole, do not form strong collaborative links. The typical relationship between supplier and customer is distant, even adversarial. Price has been the major basis for dealings with both suppliers and competi-

[12] For example, President Bush told the "Education Summit' in September that the United States "lavishes unsurpassed resources [our children's] schooling."

[13] M. Edith Rasell and Lawrence Mishel, "Shortchanging Education," Economic Policy Institute briefing paper, Washington, DC, January 1990.

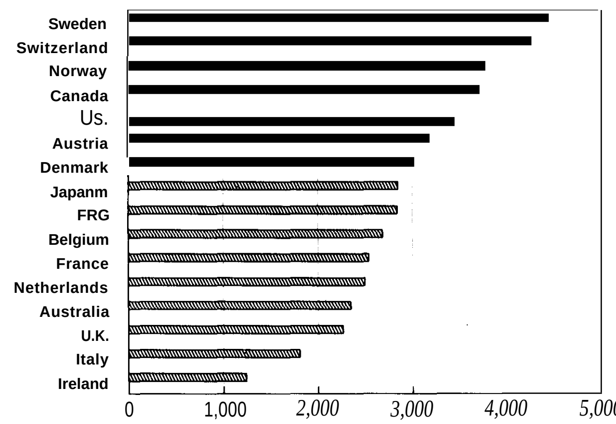
[14] The fact that prices of many consumer goods made i Japan are lower in the United Stare and other foreign countries than in Japan indicates that Japanese manufacturers do not always compete vigorously on price, Japan's complex distribution system amounts for some but not all of the higher retail price for many goods.

Figure 1-14--Spending for Education Grades K-12. percent of GDP, 1085



SOURCE: Lawrence Mishel and M. Edith Rasell, "Shortchanging Education," Economic Policy Institute briefing paper, Washington, DC, January 1980.

Figure 1-15--Spending for Education Grades K-12, Per Pupil, 1985



SOURCE: Lawrence Mishel and M. Edith Rasell, "Shortchanging Education," Economic Policy Institute briefing paper, Washington, DC, January 1990; arrd U.S. Department of Labor, Bureau of Labor Statistics, unpublished data, August 1989.

tors. This is not invariable, nor is it without advantages. In some industries-notably, the airline and aircraft industries-relationships between suppliers and customers are traditionally strong; and in some where relations used to be distant or hostile--such as textiles and apparel—they are becoming stronger. Moreover, price competition among suppliers or between competitors, is desirable and healthy. But taken too far, narrow reliance on price competition can sever close links between customer and supplier, and reduce incentives to improve quality and timeliness, Close and stable relationships with customer firms are incentives for supplier firms to invest in human resources and in equipment that may take several years to pay off. To illustrate the point, in a recent study of metalworking companies, about half the firms that had not bought numerically controlled (NC) or computer numerically controlled (CNC) machine tools cited lack of stable demand for their product as the reason.[15]

Both parent and supplier companies in Japan benefit from close, cooperative relationships. Without having to manage every detail, the parent company is able to demand favorable terms for costs, quality, and delivery times. The supplier has the advantage of a reliable customer who can provide assistance with technical problems and occasionally with finance if needed. While these relationships are often quite stressful for the supplier companies, they have promoted the diffusion of technology and know-how to Japan's myriad of small companies with remarkable effectiveness, aided by an abundance of Japanese Government technology diffusion programs. (See the following section in this chapter on ***Transferring Knowledge*** and ch. 6).

In contrast, American companies have traditionally opted for one of two strategies: vertical integration, or arms' -length dealing with competing suppliers. While vertical integration could be thought of as the ultimate in close relationships, the control over cost that a company can exercise with an outside supplier may be sacrificed. And pitting suppliers against each other—making them compete for every contract on price with no assurance of ever getting another one—makes it more difficult to transfer technology and design responsibilities. The Japanese system has been a remarkably effective compromise. A measure of its effectiveness is that

[15] Maryellen R. Kelley and Harvey Brooks, "The State of Computerized Automation in U.S. Manufacturing," John F. Kennedy School of Government, Harvard University, 1988.

many American industries-the motor vehicle industry, as well as the textile and apparel industries-are making similar arrangements with their own suppliers.

Close relations between capital equipment suppliers and their customer firms are especially important to technological prowess, particularly in fast-moving industries like microelectronics. In the past two decades, American industry has become steadily more dependent on foreign manufacturers for its production machinery. Japanese suppliers have come to dominate the market for workhorse CNC machine tools; Swiss, German, Japanese, and other European makers lead the market for textile and paper industry machinery; and U.S. producers of semiconductor production equipment are fast losing the lead to Japanese rivals.

In textile industry machinery, where the domestic market share fell from 93 percent in 1960 to less than half in 1986, the reasons for the demise of most U.S. producers are instructive. The industry's decline, which began in the 1960s, was due largely to its unresponsiveness to customer needs and to a short-term perspective, reflected in scanty spending on research and development compared with foreign competitors. The neglect of R&D spending was made worse by the merger mania of the 1960s. Most of the U.S. textile machinery companies were bought by conglomerates.

Although the decline of the American textile machinery industry has not, it seems, crippled American textile makers. Nearly all report satisfactory service from their foreign suppliers. However, the situation is different in the semiconductor industry. As recently as 10 years ago, American firms held more than three-fourths of semiconductor production equipment world market. By 1988, the U.S. share was down to 47 percent and still dropping (table 1-2, figures 1-16, 1-17, and 1-18). This year, Perkin-Elmer, one of the major remaining U.S. manufacturers of lithography equipment, dropped out of that market, which had become a money loser for the company.

Already, losses in the American semiconductor equipment industry are a handicap for U.S. semiconductor producers. U.S. producers say that, for some critical production equipment, they are unable to buy the latest model from Japanese makers only after it has been in wide use by Japanese chipmakers for months. Many U.S. chipmakers are concerned that their ability to get state-of-the-art equipment will decline further in the future. The next generation of lithography equipment is expected to use X-rays, and the Japanese are well ahead of U.S. companies in developing X-ray lithography equipment. If commercial use of X-ray lithography equipment begins, as expected, in the 1990s, it is likely that the first use will be in Japan. That development would add to the already substantial number of microelectronics technologies dominated by Japanese producers.

Sematech, the U.S. industry-led consortium to develop a process to manufacture a 16-megabit DRAM, has given top priority to improving relations between chipmakers and equipment producers. Sematech's directors see better relations as essential to develop a range of high-quality, affordable equipment and materials for American producers.

U.S. producers of supercomputers also risk dependence on Japanese suppliers of components. Significantly, many of those suppliers are also competitors, making supercomputers themselves, or else are closely aligned with competitors. For example, the highest performance memory and bipolar logic components for supercomputers come only from Japan. The management of Cray, a U.S. manufacturer of supercomputers, has at times been told that the latest and best of these components are ''not yet available for export" from Japan.[16] They are, however, available to Japanese supercomputer

[16]IEEE/USAB Committee on Communications and Information Policy, "U.S. Supercomputer Vulnerability,' report to the Institute Of Electrical and Electronics Engineers, Inc., prepared by the Scientific Supercomputer Subcommittee, Committee on Communications and Information Policy, United States Activities Board (Washington, DC, August 1988).

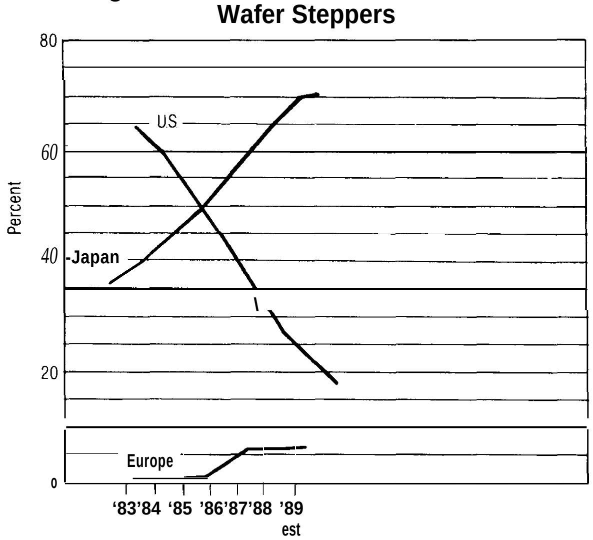
Table 1-2—Top Ten Semiconductor Equipment Suppliers, World Sales
(millions of dollars)

1982		1988	
Perkin Elmer	$162	Nikon	$521
Varian	100	*Tokyo Electron (TEL)*	*508*
Schlumberger	96	*Advantest*	*385*
Takeda Riken(Advantest)	*84*	Applied Materials	382
Applied Materials	84	General Signal	375
Eaton	80	*Canon*	*290*
Teradyne	79	Varian	211
Canon	*78*	Perkin Elmer	205
General Signal	77	Teradyne	190
Nikon	*58*	LTX	180

(Japanese Firms Italicized)

SOURCE: VLSI Research, Inc.

Figure l-16-Shift in Market Shares for Wafer Steppers



NOTE: The wafer stepper is a device central to manufacturing semlconductors.

SOURCE: VLSI Research, Inc.

makers, and the Japanese supercomputers themselves are ready for export. Closer relations with U.S. suppliers is not just an advantage but a necessity for maintaining market share, in a world where a firm's major suppliers are its fiercest competitors.

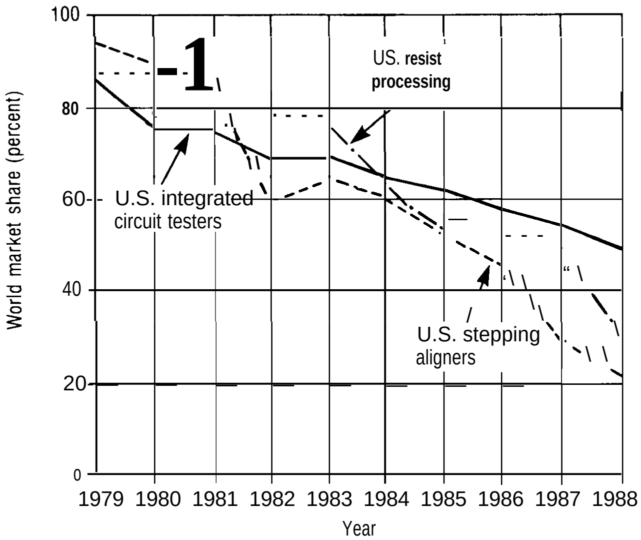
Another wellspring of Japanese technical prowess is cooperative research and development, which has the advantages of shared expenses and synergism. Participants in consortia to develop new products or techniques can gain access to research results they could not afford on their own, and have the chance to work with scientists or engineers from other firms and institutions.

Complex manufacturing processes and sophisticated products demand increasing inputs of research and development. The higher the cost of R&D, the riskier the investment-too risky, perhaps, for all but the largest and most stable fins. For example, it is costing billions of dollars to develop X-ray lithography, an amount that strains the resources of even giant firms. In Japan, a government-sponsored consortium is helping to share the risk and effort involved in developing commercial X-ray lithography.

R&D consortia have other attractions. For example, they are often effective at diffusing technology to participants; they help to avoid problems of redundancy, or wasting of resources on reinventing wheels; and they can be valuable training grounds for researchers. Especially when government is a participant, censortia can help to provide adequate investment in technologies that have a great many externalities—where the rewards cannot be captured by a single firm. In this way, consortia can help lengthen the short time horizons of American management.

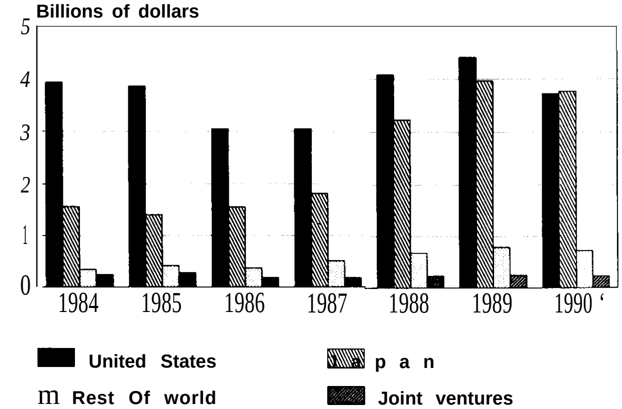
Consortia are not,of course, a panacea.They seem to work best when there are clear goals and least potential for conflict among members--for example, in catch-up projects, where no firm can hope to get a monopoly on a new technology. If America were in the competitive position it occupied two decades ago, we might well conclude that the case for stimulation of consortia (especially ones with government participation) is dubious. But that is not the situation. The

Figure 1-17—U.S. Market Shares of Selected Semiconductor Equipment



SOURCE: VLSI Research, Inc.

Figure 1-18--World Semiconductor Equipment Sales



•Forecast

SOURCE: VLSI Research, inc.

United States has serious competitive problems to solve. The European Community, moreover, has opted to support a profusion of new science and technology consortia. These consortia are largely aimed at overcoming what are perceived as substantial foreign leads in a wide variety of technologies. While the EC's technology consortia probably will never amount to more than 10 percent of all the Community's expenditure on R&D, that small percent is viewed as critical, both because it adds to the amount spent, and because it gives the EC an important strategic lever for guiding European manufacturing technology.

American industry and government have moved cautiously toward collaborative R&D in the past few years. The Federal Government put up half the funding for Sematech, and it has contributed $5 million per year for 3 years to the National Center for Manufacturing Sciences, a consortium designed to do generic research on metalworking and other manufacturing technologies. The National Science Foundation's Engineering Research Centers offer another approach. ERCs are university-based centers that get half their funds from NSF, one-third from industry—which must cooperate with the university in generating and running the research program-and the rest from university, State, and local funds. This small program encourages interdisciplinary engineering research and education and promotes cooperation among university and industry researchers.

One obstacle that sometimes hinders greater collaboration-more in downstream activities like manufacturing than in R&D--is our antitrust law. The discouragement comes not because all collaborative projects would actually violate antitrust law, but because the law is rather unclear, its penalties can be harsh, and trials are expensive. Antitrust law can also interfere with U.S. firms' merging to face competition from larger foreign fins.

These problems suggest the need for modest changes in our antitrust laws. They need to be made carefully, so as to preserve the laws' protection against price-fixing and other anticompetitive practices. Possible approaches include clarifying that conduct should be judged with full consideration of the long-term benefits of cooperation, reducing harsh penalties, and providing for advance approval of cooperative projects.

TRANSFERRING KNOWLEDGE

Public and private institutions for diffusing new technologies across the manufacturing sector are thin in the United States. In particular, there is little technical assistance available to small manufacturing enterprises. While some small manufacturers are on the cutting edge of technology-the Silicon Valley startup springs to mind-most are not. Many cannot afford to devote the time and attention to keeping up with technological developments made in the United States, to say nothing of technical advances made abroad.

It is uncommon for large manufacturers in America to lend technical assistance to their suppliers—still less for the first line suppliers to pass along technical help to smaller subcontractors. Both are everyday practice in Japan. There is little in this country to compare with Japan's dense nationwide network of free, public technology extension services for small and medium-size firms. Nor do we have anything like the huge programs of financial assistance that accompany technical assistance to small and medium-size firms in Japan. In 1988, low-cost direct loans to smaller firms from Japanese national government financial institutions amounted to more than $27 billion, not to speak of $56 billion in loan guarantees, plus additional technical and financial assistance from prefectural and local governments.

In the United States, aside from some small programs for disadvantaged individuals, the Federal government makes no direct loans to small business. In fiscal year 1989, the Small Business Administration underwrote guaranteed loans worth $3.6 billion. A few States have industrial extension services to help small manufacturers make informed decisions about improving their production methods and implementing new technology. No accurate count is available, but these State programs are probably funded at about $25 to $40 millions per year. Federal involvement in industrial extension is sketchy, although Congress has recently taken some steps to strengthen it. The Federal program of technology extension consists mainly of three Manufacturing Technology Centers created in the Omnibus Trade and Competitiveness Act of 1988 and funded at $7.5 million in fiscal year 1990; three more centers are planned. Altogether, current industrial extension programs, State and Federal, reach only a small fraction—probably less than 2 percent per year-of the Nation's small manufacturing firms.

Government technical assistance to small manufacturers in Japan far outpaces similar programs in America. Because financial and technical assistance programs are interrelated, an estimate of the size of these programs is not available, but they are large. For example, Japan's national government provides half the funding for the nationwide system of 185 technology extension centers with the other half provided by prefectural governments. Total funding for the centers is over $470 million per year. Local governments support additional technology extension centers as well. But government assistance is not the only or even the major form of technical assistance. In a recent survey done by MITI's Small and Medium Size Enterprise Agency, 45 percent of respondents (small and medium-size businesses) reported that they received technical assistance from a parent company, 37 percent got information, 28 percent were loaned or leased equipment, and 24 percent got training for their employees.[17] In some cases, vertical transfer of technology within Japanese supplier groups is effective enough to allow major manufacturers to delegate other functions to their suppliers. Both Toyota and Nissan, for instance, have delegated assembly of some of their cars to former first-tier suppliers.

American companies—including all the Big Three motor vehicle companies—have instituted similar programs recently, becoming both

[17] D.H. Whittaker, "New Technology Acquisition in Small Japanese Enterprises: Government Assistance and Private Initiative," contractor report prepared for the Office of Technology Assessment, May 1989, p. 23.

more demanding and more supportive of their suppliers. They have pared down the numbers of suppliers, given more technical assistance, and are moving towards performance-based standards. But U.S. firms are still far behind Japanese manufacturers in diffusing technology and know-how along supplier chains, or among firms within an industry, or from public institutions to private fins.

Because of Japanese direct investment, some American firms are experiencing the Japanese system firsthand. According to a recent GAO study, U.S. auto parts producers who work with Japanese transplant assembly firms report that their Japanese customers keep in closer contact than their U.S. customer firms, and send many more staff on site visits to the supplier's plant. They characterized the Japanese companies they work with as ''preventative' in solving problems, rather than "reactive," like American firms.[18]

Large U.S. firms as well as small ones suffer from isolation. Their customary arm's-length, adversarial relation with suppliers deprives them of the back-and-forth collaborative work on new technologies that takes place between large firms and first-line suppliers in much of Japanese manufacturing. This collaboration is important to innovation in Japan. Japanese manufacturers of all kinds of products, from automobiles to office copier machines, are quick to make incremental changes in products and bring new models embodying the latest technology to market ahead of their competitors.

Another contributing factor to firms' competitive position is their readiness to scan the world, find out what new technologies are available and plug them into new products. American firms seem much less inclined to exploit technologies that originate outside the fro-a stance often called the not invented here (NIH) syndrome. One study of 50 large Japanese firms and 75 large American firms found that Japanese firms spent considerably less time and money than the U.S. firms in developing new products and processes, mostly because the Japanese were adept at exploiting innovations made elsewhere, while American firms were trying to generate more of their innovation internally.[19] The ability to make effective use of external technology is also related to short product cycles. Japanese firms in automobiles and electronics have managed to pare product cycles so that they are shorter than those of American competitors. Since new ideas, from inside or outside, are most likely to be adopted at the beginning of a product cycle, shorter cycles mean more innovation—and they do, for many Japanese industries.

The reluctance of U.S. firms to adopt and work with outside ideas has not undermined their ability to apply big-bang, fundamentally new technologies that can be exploited commercially. American companies in general have been good at this, and many small startup firms have found venture capitalists to stake them. NIH applies more to technologies that are good for incremental improvements. It may also help to explain why U.S. firms take curiously little advantage of new technologies developed in Federal laboratories. However, another reason is that the labs, short of money for technology transfer and hampered by red tape, do not reach out to industry.

Most of the $21 billion per year spent on R&D in Federal labs is for defense or basic research-missions not directly relevant to commercial manufacturing. Some of this R&D could be made useful to civilian manufacturing, both by transferring lab technology to industry for further development and by lab-industry cooperative R&D on subjects of mutual interest. Although Congress passed several bills in the 1980s to encourage commercialization of technology from the Federal labs, such commercialization has been modest.

[18] U.S. General Accounting Office, Foreign Investment: Growing *Japanese Presence in the U.S. Auto Industry*, GAO/NSIAD-88-11, March 1988.

[19] Edwin Mansfield, "Industrial Innovation *in* Japan and the United States," *Science*, Sept. *30*, 1988.

One main reason is that the labs' efforts at encouraging commercialization have not been adequately funded. Without line-item funding, such efforts are often considered by personnel at the labs and their parent agencies to be mere distractions from their primary missions. Interactions between the Federal labs and private industry require a new philosophy and new procedures, and the resolution of some difficult issues (e.g., potential conflicts of interest). Resolving them is more difficult when agency officials, such as the general counsel, put forward objections and there is no strong countervailing voice to push the process along. In addition, some provisions of the law hinder the labs from granting a firm exclusive rights to technology. Without those rights, firms may not find it worth their while to commercialize technology coming out of the labs.

Concerns about exclusive rights extend to R&D in general. Many American firms complain that in the United States and, especially abroad, their new products and manufacturing processes are copied by imitators who did not pay to develop them. They desire stronger intellectual property protection for new technology-chiefly patent rights, and copyrights for software. Without it, they assert, they face unfair competition and cannot pay for their R&D.

This argument has some merit, and some measures to increase protection would help. The most promising ones include strengthening patent enforcement in the United States and Japan, and negotiating to harmonize and eventually unify the patent systems of different countries. However, there are limits to the benefits to be expected from beefing up intellectual property protection. Developing countries may be induced to add some protection but, on the whole, they do not see stronger measures as in their interest. More generally, strong protection, while encouraging creation of technology, can inhibit its diffusion and, in the long run, cannot make up for disadvantages in manufacturing quality and cost. Therefore, while stronger intellectual property protection can help U.S. manufacturing competitiveness somewhat, measures to improve manufacturing quality and cost will help more.

POLICY ISSUES AND OPTIONS

In building a stronger technological base for American manufacturing, both industry and government have important parts to play. Many of the things that must be done are squarely up to manufacturers themselves. Company managers have to learn to use their people more effectively by promoting a back-and-forth flow of people and ideas between research (or design) and production, insisting on design for easy manufacture, pushing simultaneous engineering of improved products and the processes to make them, and giving shopfloor workers the training and responsibility for improving efficiency and product quality. Likewise, it is managers' job to get the fat out of the American production system—for example, by trimming inventories that cost money and hide problems, and by organizing work for reduction of waste. And it is largely up to managers to make the most of forming cooperative relationships between large firms and their smaller suppliers, or between different segments of an industry complex.

There is also much that government can do. Traditional U.S. R&D support, mainly for defense and science, has been beneficial to the Nation as a whole and often to industry in particular, but it is not enough to maintain technological leads, or even parity, in most industries-especially since most of the other OECD nations are making greater efforts to advance civilian technology.

First, government policies that create an environment more conducive to manufacturing make it easier for companies to concentrate on the things that only *they* can do to improve technology. For example, if government policies succeed in lowering the cost of capital to business, or lifting some of the pressure for short-term profits, they are "preparing the ground' (as the Japanese say) for business to do its job well.

Government can also take more direct actions, some within traditional U.S. policy, and others less so. Starting with broad policies affecting the financial environment and human resources, they could go on to stepped-up programs for active diffusion of technology to private firms and, still further, to a strategic approach that would target government R&D support to critical technologies.

The possibilities for government action do not stop there. Many governments throughout the world use means beyond R&D support to promote industries they consider strategically important. For instance, they may favor certain industries with low-cost capital or government-guaranteed purchases, and they may add further support with trade policies designed to manage competition from dominant foreign producers during developmental phases. In building up its industrial might, Japan relied heavily on coordinated technology, industry, and trade policies to promote key industries. Korea and Taiwan followed Japan's lead, and the European Community is using many of the same industrial and trade policy tools as it prepares for the European single market in 1992.

Whether the United States should or even could try to use such comprehensive government policies to bolster competitiveness will be considered in another report, the final one in OTA's assessment of Technology, Innovation, and U.S. Trade. That report will discuss industry and trade policies of Europe and the Asian rim countries, and in what way they might be relevant to the United States.

In this assessment, the spotlight is on technology. The policy options analyzed in chapter 2 and summarized below are directed toward four principal strategic aims:

- Improving the financial environment for U.S. manufacturing firms. This means lowering capital costs and relieving other pressures in the financial markets to show high short-term profits every quarter. The goal is a more hospitable environment for long-term investment in new technologies and productive equipment.
- Upgrading education and training of the workers, managers, and engineers needed in manufacturing. U.S. manufacturing suffers from the failings of our public schools, but also from failures of managers in organizing work and training people to use advancing technologies effectively. Besides continuing efforts to improve education generally, government can help with the retraining of active workers and the betterment of manufacturing engineering.
- Diffusing technologies throughout the manufacturing sector. Government can be much more active than it has been up to now in helping manufacturers acquire up-to-date production equipment and learn to use it effectively. Options might include stepped-up Federal support for technology extension services and a subsidized equipment leasing system. Such things as easier access to technologies coming from Federal labs or foreign countries could benefit all U.S. manufacturing.
- Supporting R&D for commercially important technologies. Some technologies of great potential benefit to society do not get adequate private backing because the payoff for individual firms is too small, uncertain, and far in the future. The U.S. Government has sometimes given special support to R&D for commercially important technologies, but in an ad hoc rather than proactive way. A coherent, strategic technology policy require having an agency in charge that can set goals and choose technologies to support that fit the goals.

Improving the Financial Environment

To keep up with the competition, U.S. manufacturing firms need two basic things that are mainly the province of government to supply: well-educated workers and capital costs that are not so high as to be disabling. As matters stand, government in this country is not doing well at supplying either of these necessities.

The combination of massive government dissaving (the Federal budget deficit, at historic highs in the 1980s) and anemic personal and business saving (at historic lows in the 1980s) is a powerful force driving up interest rates and the cost of capital to business. Congress has made some progress in reducing the Federal budget deficit but it remains high. Some combination of higher revenue and lower spending over several years will be needed to reduce the budget deficit, and this poses a problem. Many of the policy options suggested in this report would, all other things being equal, have a contrary effect, because they would entail either increased tax expenditure or reduced revenue. If these or other policies are not to have the perverse effect of increasing the deficit, even stronger measures would be needed to reduce it. If the United States succeeds in restoring its strong competitive position, then economic growth will help to shrink budget problems in the future. There will be a price to pay in the short run for improving manufacturing, but if it restores our ability to raise standards of living for the great majority of Americans in the long run, it will be worth it.

The budget deficit is a significant source of upward pressure on interest rates, but not the only one. To make capital less costly, the supply available for capital formation must also be expanded. That means raising domestic savings rates. Although the personal savings rate has risen from its extreme low in 1987—less than 2 percent-it is still below the U.S. norm of 6 to 8 percent, and far below the rates in Japan and most European countries. Some analysts argue that the United States can continue to rely on foreign capital to make up the difference between domestic investment and domestic savings, but that is inconsistent with lowering capital costs. It takes high interest rates to attract foreign capital.

To encourage household savings, Congress could consider a national savings initiative, which would reward increases in regular savings (e.g., payroll savings) for households in all tax brackets. To be effective, such a campaign would need to include several substantial savings inducements, such as guaranteed interest rates, high enough to be attractive, on widely available savings instruments. One suggestion is for anew type of government bond with a fixed coupon rate. Reducing taxes on the interest income to regular savings could also be considered.

Inducements to save may not be sufficient to raise savings rates or promote capital formation in industry without some accompanying measure to discourage consumption. Congress may wish to consider a consumption tax, scaled to tax luxury items most heavily, or with substantial exemptions to avoid the severe regressivity of a flat consumption tax. Another possibility is to limit the deductibility of interest paid on home mortgages more severely. There are some limits now, but they are set very high; this encourages consumption of housing and builds equity for households, but the capital tied up in housing is not available for industrial capital formation.

The measures suggested above could help to bring down interest rates generally, and that would tend to lower capital costs. Interest rates and capital costs are not synonymous, however; capital costs are also a function of taxes and of relationships between capital suppliers and companies. Several measures could help to lower the cost of capital to U.S. companies even if general interest rates remain high. One set of options Congress might wish to consider is special tax inducements for technology development and capital investments. The United States has tried a few such measures in the past. For example, the Accelerated Cost Recovery System (ACRS) and the Investment Tax Credit (ITC) were designed to promote capital investment, and the research and development tax credit to increase R&D spending. While the effectiveness of these measures is debated, there is enough substance to the arguments in their favor that they (or measures like them) are worth considering. And they should be considered separately, for they are very different. ITC and ACRS were very expensive (costing tens of billions of dollars, when they were in full force); such measures could, if designed carefully, promote mainly

improvements in manufacturing technique. The R&D tax credit is far less expensive, and has more effect on new technology development than on current practice.

Another set of forces affecting capital costs, especially for long-term investment in technology development and capital equipment, is the current wave of hostile takeover activity and speculative turnover of stock. This activity, and the threat of it, reinforces the effect of high capital costs in impelling managers to focus on short-term profits. The relative influence of the takeover boom and high capital costs is a controversial matter which OTA does not resolve. Nonetheless, it is reasonable to conclude that takeover activity is a significant damper on managers' willingness to commit resources to long-term projects, or to retain earnings for reinvestment. The pressure from this source might be manageable if overall capital costs were lower, or if there were enough effective countervailing measures to promote higher levels of investment in R&D and capital equipment purchase.

As it is, Congress might wish to consider mitigating the pressures of hostile takeover activity by means of incentives for investors to hold investments longer. This might be done by adjusting the capital gains tax rate to favor long-term gains and penalize short-term asset turnover. This measure would have most effect if the tax were extended to pension and other funds that are currently tax-free, but account for more than half the transactions in the financial markets. Another option is to tax securities transactions, which would penalize those whose turnover is greatest. However, without real, steady progress toward eliminating the budget deficit, all of these other measures taken together will probably have only a marginal effect.

Finally, the financial environment of the United States is unstable and unpredictable, compared with our premier international competitors, Japan and West Germany. In Germany, in particular, macroeconomic policymaking concentrates on maintaining stability in prices and exchange rates and controlling inflation. Such stability is an enormous asset to business, especially in a country that is heavily dependent on foreign trade (like West Germany), and especially when supplier-manufacturer-customer links are increasingly likely to span national borders (as the 1992 European Single Market approaches).

Japan's financial environment is also very stable. Policymakers there are highly sensitive to how macroeconomic developments affect business, and they take steps to help the private sector adjust. For example, after the international financial accords were reached to raise the value of the yen (and other currencies) against the dollar in the mid-1980s, the Japanese Government put in place loan programs to help firms (small ones, in particular) adapt to the rising yen (endaka). Japan's economy did slow down in 1985 and 1986, at the beginning of endaka, but the adjustment was swift. Much more painful were the circumstances faced by American manufacturers in the early 1980s when the dollar began its long climb, and no government policy was in place to ease the adjustment. In sum, a major difference between Japanese and U.S. policies is that little concern is evident in the United States about the effects of macroeconomic, trade, and other policies on the competitiveness of U.S. firms in general or manufacturers in particular. In Japan and West Germany, competitiveness is customarily taken into account. It plays a prominent role in making and implementing those governments' policies.

Human Resources

Human resources, like capital costs, have a pervasive effect on manufacturing. In the past, most manufacturing workers learned their jobs by the sides of more experienced workers, and an ordinary grammar school or high school education was plenty of preparation for a production worker in manufacturing. Today, with automation affecting more workplaces and less automated work being exported overseas, production jobs in manufacturing require more conceptual knowledge-and often competence

in statistical process control and managing computerized equipment. Jobs typically encompass more diverse tasks than in the past, and workers must grasp the relationships of different parts of production to each other in ways never required before. In other words, more is demanded of manufacturing workers. At the same time, the typical American education is leaving young people less well prepared for their worklives. Managers have remarked for years that young people could be better prepared, but the situation now is commonly described as a crisis. And it is likely to get worse before it gets better. About half the new entrants to the work force between now and the turn of the century will be members of minority groups, and about two-fifths of minority children live in poverty. Poor children typically drop out of school in disproportionate numbers, and many grow up lacking the skills they need to be productive workers.

There is a broad consensus that the Nation's public school system needs help. But even if help arrived tomorrow, the results would be many years coming. A more immediate approach is to help people already in the work force to acquire needed skills. While some large companies are providing education and training themselves, the financial burden of such programs-good ones can run into hundreds of thousands to millions of dollars-is another drain on limited financial resources, Most small companies cannot afford extensive training programs.

Congress could consider several options to help workers raise their educational levels and improve their work skills. One is to offer federally guaranteed student loans to employed people taking classes part-time; another is to let employers and employees deduct the costs of training and education (the present tax law already allows this, subject to some limitations). Another possibility is to tailor military training programs, which are already extensive, to fit more closely the skills required of workers in civilian jobs. The Federal Government provides less than $10 million to a program that partially funds demonstration projects for literacy teaching in workplaces. There is ample evidence of additional demand for such projects; increased funding could be used effectively and immediately. Training could also be made a part of any technology extension services offered by the Federal Government or funded in part by Federal money, (See the section below on *Technology Extension.)*

These suggestions do not constitute a complete list of options for training active workers. A fuller examination of the possibilities for congressional action will appear in a forthcoming OTA report, *Worker Training: Implications for U.S. Competitiveness.*

Although well-educated and trained production workers are essential to improving manufacturing efficiency and quality, there are other, equally critical needs for highly trained people. Production workers are a steadily falling percentage of manufacturing employment; professional and technical employees are a growing share. Engineers, in particular, are essential for excellence in manufacturing. It could be more difficult in the future to maintain an adequate supply of engineers to sustain manufacturing.

There is not now an obvious shortage of engineers in manufacturing; about as many engineers are employed per thousand workers in the United States as in Japan and Germany, whose manufacturing is justly famous for its excellence. But Japan is graduating more engineers per capita than the United States, and Germany has what is probably the world's finest set of training institutions to provide technical people for manufacturing, from the shopfloor to the engineering workstation. Meanwhile, in the United States, the demographic group most inclined to enter engineering—white males-is shrinking as a proportion of young people.

This trend is not new. Several Federal programs, are already in place to encourage women and minorities to enter engineering. Larger programs support the recruitment and training of students generally in scientific and technical careers, and special training for teachers.) Many of these programs are producing good results

and could be expanded. But without improvement in math and science education in the elementary and high schools, their effects are bound to be limited. Children who perform poorly in elementary school arithmetic and math are unlikely to choose engineering careers. General education improvement, especially in math, is the first necessity for keeping the engineering pipeline filled.

Some possible programs could help shore up the supply of engineering talent for the next few years, before improvements in education (if they are made) begin to yield results. If defense programs wind down as expected over the next few years, Federal programs might help retrain and equip engineers who have been working in the military sector to enter civilian manufacturing. More generally, programs to encourage or fund midcareer training of engineers whose knowledge needs updating might be considered.

The effective use of engineers is at least as important as an adequate supply. There are indications that U.S. manufacturers could make better use of their engineers. Elitism among engineering staffs, and their aloofness toward shopfloor problems in producing their designs, are often cited as a peculiarity of American manufacturing. This kind of problem is best solved by manufacturers themselves, but the Federal government could encourage manufacturers to recognize and correct the problem, through support of education and research in manufacturing engineering. One option is to increase Federal support of manufacturing engineering, possibly through the creation of a Manufacturing Sciences Directorate in the National Science Foundation.

Diffusing Manufacturing Technology

Making the financial and human resource environment more conducive to improved manufacturing quality, efficiency, and technology may not be enough. American manufacturers have lost too much ground to foreign manufacturers, in nearly every sector. Even with lower capital costs and more competent people, some manufacturers may still lack the resources or the knowledge to find or develop and implement the best technologies.

Congress might consider an array of options to promote technology diffusion and transfer more widely, or remove obstacles to diffusion. None, by itself, will make a great deal of difference; patience and an experimental approach will be required to make any of them work. Some may fail. Yet it is likely that some combination of policies to promote technology transfer could pay off handsomely, given time, the commitment to adapt to changing circumstances, and the willingness to learn from experience.

Technology Extension

Large firms generally have the resources to develop or acquire technologies they need, although they may neglect to take what they could from outside the firm. But many small firms have a hard time staying abreast of advancing technology. Americans like to cherish the notion that all small firms are like Silicon Valley startups—technically and scientifically advanced, staffed and run by entrepreneurial innovators—but the image is hardly typical of small manufacturing fins. For many of America's 355,000 small and medium-sized manufacturing fins, exposure to new technologies is haphazard, and the effort to keep informed is beyond their means.

To contribute to the competitiveness of U.S. manufacturing, small firms need to keep up with technology as much as large ones. While small enterprises are usually not heavily involved in foreign markets themselves, their performance is important to the ability of larger manufacturers, who are their customers, to compete. Large auto companies, for instance, depend on the ability of their myriad suppliers, some of which are quite small, to deliver the right components, well made, on time. As specifications become more exacting, and the tolerance for defects decreases, the demands for small firms to use new technologies effectively grow. America's most adept competitors, Japan and West Germany, have broad, deep institutions that support

technology diffusion and transfer to small enterprises.

Large firms can transfer technology to smaller companies quite effectively themselves. Even in Japan, however, an extensive network of government programs and institutions to support technology diffusion and training supplements these private efforts. The United States, in contrast, has a few State programs and, until recently, very little at the Federal level. In 1988, the combined technology transfer and technology/management assistance programs of the 30 States that had such programs came to $58 million, and that included assistance to all kinds of business, not just manufacturing. State industrial extension programs, giving one-on-one technical advice to individual firms, probably add up to about $25 to $40 million per year.

The Federal programs include: 1) three existing and three more planned Manufacturing Technology Centers to demonstrate advanced technologies and provide extension; 2) some assistance to State programs; and 3) the Advanced Technology Program, a mechanism for Federal guidance and participation in joint R&D ventures with private firms. Together, the three programs have funding of less than $19 million for fiscal year 1990. A smattering of other Federal programs also offer some technology extension services; the largest of these is Trade Adjustment Assistance for firms and industries, funded at less than $10 million in fiscal year 1990. These small, scattered programs contrast with billions of dollars' worth of financial and technical assistance to small and medium-sized enterprises in Japan, plus Japanese Government participation in dozens of R&D efforts. While precise comparisons of funding for technical assistance to small manufacturing enterprises are impossible, it is certain that Japan's commitment to upgrading the level of technical ability in small firms is more than an order of magnitude greater than that of the United States. (See chs. 6 and 7 for details of the Japanese and U.S. programs.)

If Congress wishes to deepen its commitment to upgrading technology in small and medium-sized manufacturing enterprises, it could increase funding for the Manufacturing Technology Centers, provide more money for State industrial extension services, or some of both. Manufacturing Technology Centers are managed by the National Institute for Standards and Technology, as authorized by the Omnibus Trade and Competitiveness Act of 1988. They are responsible for transferring technologies developed at NIST to manufacturers, making new technologies usable by small firms, providing technical and management information to small firms, demonstrating advanced production technologies, and making short-term loans of advanced manufacturing equipment to manufacturing firms with fewer than 100 employees. Although funding was authorized at $20 million per year, appropriations have been much smaller: $5 million in fiscal year 1988, $6.85 million in 1989, and $7.5 million in 1990. These amounts cover administration as well as technology extension activities. The three existing Centers have each received $1.5 million per year for their first 2 years, and must match the Federal funding. Federal funding starts to decline after 3 years, and drops to zero after 6 years.

In addition to the Manufacturing Technology Centers, the 1988 trade act authorized a program of Federal assistance to State technology agencies, administered by NIST. This program received no funding until fiscal year 1990, when Congress gave it $1.3 million to help States with industrial extension programs expand those programs. States receiving Federal money from this program must match it with their own funding.

Only a few States have real industrial extension services. (NIST, in a nationwide study, found only 13 that met their definition of "technology extension services," but more have since been established.) Several of those are quite new. Nonetheless, State programs are generally better developed than Federal ones, and a very few have years of experience.

There is room for expansion of both State and Federal efforts in technology extension. States may do abetter job of service delivery, being in better touch with the needs of local manufacturers. But there may be some things the Federal Government can provide that States cannot. By their nature, industrial extension offices specialize in the industries most prominent in their service delivery area. And industries tend to be regionally concentrated, spanning State lines; Federal services are often better suited to serve regional concentrations of industries. Also, while some State programs are excellent, others are less so; a Federal service could help ensure consistent quality of service, or at least minimum standards. If Congress wishes to consider expanding efforts in support of industrial extension, financial support for good State programs, as well as technical and financial support for States which are new to the effort, would be an effective combination with support of Federal extension services.

If Congress were to set a minimum goal of extending industrial extension services to 24,000 small firms per year nationwide (7 percent of the nation's 355,000 small manufacturers), the total cost would be $120 to $480 million, depending on the level of service. If the Federal share of funding were 30 percent, as it is in the Agricultural Extension Service, the cost to the U.S. Government would be $36 to $144 million. That would provide a modest level of service, one that might easily be overwhelmed by requests for assistance. The State of Georgia's experienced, effective industrial extension program serves a roughly similar proportion of its manufacturers, and Georgia Tech, which operates the service, reports that it does not advertise because it would be swamped with requests it could not meet. However, considering the inexperience of State and Federal Governments in providing industrial extension, moderate annual increases may be all that could be handled now.

Financial Aid for Modernizing Manufacturing

Technical assistance to small business is often most useful if it is accompanied by financial aid. Improving the general financial climate for investment or offering special incentives to invest in research, development, and capital equipment, will help all businesses. But small businesses still have special problems raising capital. They usually must pay more for both debt and equity capital, and they often do not have enough retained earnings to finance modernization programs or training on their own. Without help in financing, small firms may not be able to implement the advice of industrial extension services.

In fiscal year 1989, the Federal Government made 47 million dollars' worth of direct loans to small businesses run by special groups (disabled veterans, the handicapped, and others), and guaranteed $3.6 billion in commercial loans to small businesses. It contributed $154 million to investment corporations, which make equity investments and long-term loans to small businesses. These programs are not confined to manufacturing. None is aimed at improving the practice of manufacturing in general.

These programs are in striking contrast, both in funding and in purpose, with Japan's financial assistance to small and medium enterprises (SMEs). Japan's SME programs spend $27 billion annually indirect loans and an additional $56 billion in loan guarantees. Again, this funding is not confined to manufacturing (which makes it comparable to the figures given above for American programs). Much of the Japanese funding is tied to technical assistance, and some is directly targeted to technology improvement. Part of the reason for such heavy support to SMEs in Japan is that for many years, small business was a technological backwater. The same is true in many sectors of American small business.

There are, of course, important differences in manufacturing in Japan and the United States. One is that small firms play a bigger role in Japan's manufacturing sector-74 percent of manufacturing employment is in small and medium-size firms in Japan, compared to 35 percent in the United States. However, because

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of the larger size of the U.S. economy, the difference is less in absolute terms. Small Japanese manufacturing firms employ 10.7 million people, compared to 6.8 million in the United States. In both countries, small manufacturing plants play key roles as suppliers to the large corporations that are major actors in the world economy. And in both countries, small manufacturing fins' needs for technical and financial assistance have much in common.

Congress might consider several options to encourage firms to invest more in advanced technology and in training support required in the service and to use the technology well. One option is an equipment leasing system that would make new production equipment available to manufacturers on below-market terms. If the system bought U.S.-made equipment could serve two related purposes: besides enabling firms to get advanced equipment on easier terms, it could also help assure U.S. makers of production machinery a market for at least part of their output. In both ways, the program would help American manufacturers to focus more on long-term investment and improvement. The program could be open only to small manufacturing business, or to all manufacturers, possibly with more favorable terms for smaller firms.

Another option to encourage technological improvement in small business is more direct financial support. As noted above, the government's financial support (loans, loan guarantees, and investments in development corporations) was about $3.8 billion in 1989. This compares with $487 billion in fixed investment (structures and producers' durable equipment) by all private business in the same year. While exact comparisons with Japan are not possible, we do know that Japanese loan and loan guarantee programs to small firms area at *least* 20 times greater than those of the United States, and the level of subsidy in Japan is more substantial. For example, even a federally guaranteed loan to a small business in the United States may be a couple of percentage points above the prime rate, while in Japan, government-guaranteed loans to small business are typically substantially below market rates, and in some cases interest-free. While Japanese policies clearly are not a template for American action, they do make a difference in the competitiveness of Japanese industry at all levels.

Greater financial aid for small manufacturers could offer an opportunity to upgrade technology. One qualifying condition for financial aid (either direct loans or loan guarantees) could be that the firm receive a technical assessment, possibly from an extension service, and that it either follow the guidance of the assessor or work out an alternative plan. This is not necessarily intrusive. From the late 1970s through 1989, hundreds of small U.S. firms injured by import competition received technical help from a small U.S. Government program, Trade Adjustment Assistance for firms.[20] (The program, formerly funded at about $15 or $16 million per year, including assistance to industries as well as firms, has been substantially reduced. Its fiscal year 1990 funding was $9.9 million in new and carryover funds.) An assessment was a precondition for assistance under the program, and many participating firms found it a valuable service. Many small firms in Japan voluntarily undergo assessments each year in order to learn of new techniques and markets, and to get an independent (though not detailed) assessment of the directions competitors are taking. This option presupposes an industrial extension service that could deliver competent, timely service nationwide.

Another possibility is to target financial aid to investments in advanced equipment, as Japan has done several times. Recently, for example, producers were allowed to depreciate automated electronic ("mechatronic" equipment very rapidly, encouraging many small and medium-

[20]For a description and analysis of the program, and the larger and better known program of Trade Adjustment Assistance for workers, see U.S. Congress, Office of Technology Assessment, *Trade Adjustment Assistance: New Ideas for an Old Program*, OTA-ITE-346 (Springfield, VA: National Technical Information Service, 1987).

sized firms to acquire numerically controlled machine tools. A drawback is that some firms might invest in equipment they aren't prepared to use properly; but a technical assessment or industrial extension service could help here.

Financial and technical assistance to small firms could be explicitly extended to cooperatives of small firms as well. Managers of small fins, with too few staff to dedicate even one person to keeping up with technology-or for that matter, with competitors, customers, or suppliers-often have to depend on a few ad hoc sources for information about changes that affect their business. Cooperative networks can help these managers in many ways, by pooling the time and resources needed to keep up with technology, changing markets, customers' needs, and competitors' doing by obtaining quantity discounts on equipment that individual firms buy in ones or twos; and by providing an independent source of information on new technologies that does not have its own commercial interests at stake, as vendors do.

If Congress wishes to support the formation of cooperative associations, it could consider making the services of federally funded industrial extension services available to cooperatives, or extending financial assistance to cooperatives as well as firms. Congress might also want to make provision for small firms to cooperate in marketing and manufacturing without risking violation of the antitrust law.

Commercialization of Technology From Federal Laboratories

The Federal Government spends $21 billion each year on R&D in Federal laboratories, of which three-fifths goes to defense applications. Some of the defense R&D could be useful to civilian industry, along with some of the basic research done for nondefense applications in Department of Energy (DOE) laboratories. For example, industry has benefited from using specialized facilities at some DOE labs, such as the Synchrotrons Light Source at Brookhaven National Laboratory and the Combustion Research Facility of Sandia National Laboratories.

On the whole it has not been easy for industry to take advantage of the labs' technology—despite legislation enacted throughout the 1980s to facilitate the process. There are still obstacles on the Government's side, and further measures by Congress could help, although ultimately success will depend on industry's willingness to tap into the labs.

Congress could consider earmarking some of the labs' R&D appropriation for promoting commercialization. This would include identification and marketing of promising technologies, patenting when appropriate, and cooperative R&D projects to bridge the gap between the laboratory and commercial exploitation. Earmarking some funds for cooperative R&D could be particularly beneficial. (DOE's high-temperature superconductivity pilot centers in three national laboratories are examples of cooperative R&D projects, planned from the start with industry and funded 50-50 by industry and the labs.) Congress might begin by mandating that a few percent of the labs' budgets be set aside for cooperative projects as appropriate. This would encourage labs to seize opportunities for cooperative work promptly.

Another possibility is increased funding for the Federal Laboratory Consortium. The FLC, with a small central staff and volunteer representatives from over 300 labs, tries to match inquiries from firms with the appropriate lab researcher. Additional funding could help the FLC to perform this function, and also to increase its projects demonstrating new means of technology transfer.

In addition, Congress could consider measures to remove several obstacles to technology transfer and cooperative R&D. For example, DOE's national labs have sometimes been stalled by Agency red tape when they wish to license technology to firms. Congress has already taken some steps to give the labs more independence in this regard and could go further (e.g., by extending to all labs the power to take automatic title to patents from lab research, removing the necessity to wait for extended

agency review). To make cooperative projects more attractive to industry. Congress could also clarify DOE's right to keep information developed in the projects proprietary, and allow copyright of computer software created by government employees involved in such projects.

Lab-industry cooperation raises several other issues, such as possible conflicts between lab employees' duties at work and their desire to get consulting work or royalties from the commercialization of their work. Congress could consider forming an interagency legal task force which could give a broader perspective than a single agency has on these and other legal issues raised by lab-industry cooperation. The task force's approval would not be required; but an agency's general counsel, if concerned about an issue, could seek the task force's advice.

Tapping Into Japanese Technology

American firms are often faulted for not making greater efforts to investigate and import technologies developed elsewhere—sometimes, even in another division of the same firm. When U.S. firms were technologically dominant in most industries, this parochial attitude was no great handicap. Now, with technological advantage more evenly distributed around the globe, it is a significant hindrance. Many firms have responded to the challenge to keep up with technology developed abroad, but they face special difficulties getting access to Japanese technologies. One is simply the language. European languages are enough like English, and enough Americans know some European language, that it is not too hard to get the gist of technical articles or to have them translated. But the Japanese language poses much more serious translation problems. Another difficulty is that much of Japanese technology is developed in the industrial sector and thus is inherently less accessible than technical expertise and knowledge freely available at universities and other public or quasi-public institutions.

A sprinkling of U.S. programs promote technology transfer from Japan. A few universities have fellowship programs that send graduates in science and engineering to Japanese companies and research institutions; and the National Science Foundation and the Government of Japan sponsor several new programs to support long-term research by U.S. engineers and scientists in Japan. The NSF-Japan programs were not fully subscribed as this report was written, although there is reason to believe that they will attract more applicants as they become better known. Congress may wish to monitor the progress of government-supported programs, and provide additional funds when and if they become overcrowded.

Other options are to establish a Congressional U.S.-Japanese Fellowship Program, and to encourage government researchers working in Federal labs or elsewhere in the Federal Government to undertake long-term projects in Japan. Postdoctoral or midcareer fellowships for professionals other than scientists and engineers could also be useful, not in directly transferring technology, but in helping more people to understand the workings of Japanese management and government-industry relations.

Congress might wish to consider increasing the funding for the Office of Japanese Technical Literature. While demand for the office's products has been disappointing, expanding the services available could create more interest. Finally, the government could promote Japanese language instruction in public schools, possibly by examining the critical foreign languages program in the 1988 education act to see if it gives sufficient weight to Japanese. Another option is to fund expansion of Japanese language programs in post-secondary and postdoctorate education, especially for scientists and engineers.

Antitrust

Antitrust law and enforcement have been relaxed in the past decade, but fear of running afoul of antitrust statutes is still a potent force in industry, because the law is complex and often vague, penalty for violation can be stiff, and private parties as well as the government can

bring suit under the laws. There is good reason for firm enforcement of antitrust law; for many years, it has served this country well in maintaining competition. However, some kinds of cooperation among firms could help American competitiveness, and some modest changes in antitrust law and enforcement could help promote them.

Congress has already amended and clarified the law to make some joint activities easier. Among other provisions, the National Cooperative Research Act of 1984 clarified that joint R&D (as defined in the Act) will be judged under the rule of reason if suit is brought. This rule ensures full consideration of the activity's pro-competitive effects. Congress might wish to consider extending this provision to joint manufacturing and standards-setting. The 1984 Act also reduced private treble damages to single damages for registered R&D projects. Congress might wish to consider reducing treble damages in other circumstances as well.

Advance certification for some kinds of joint activities is another option. Firms could apply to the Justice Department for a determination that a proposed project complies with antitrust law. Private parties could challenge that determination in court but could not collect damages for activity covered by it. Another possibility is to establish safe harbor market shares, below which firms would not be in violation. Finally, Congress could make findings that joint ventures or mergers between U.S. firms are sometimes necessary to fend off foreign competition, and could instruct courts to evaluate such activity based on long-term effects.

Whether modifying the antitrust laws or their enforcement would unleash a great deal of cooperative work, and whether such changes would substantially improve manufacturing competitiveness, is unknown. It is also unknown whether changes such as those suggested would have substantial negative effects from lessening the fear of antitrust suits-effects such as increased hostile takeover activity or more price-fixing. Changes in antitrust law and enforcement should be made cautiously, but they deserve serious consideration.

Innovation and Intellectual Property

Improvement of intellectual property protection could well start at home. Within the United States, the greatest complaint is that patent enforcement is slow. Patent cases that go to trial take, on average, more than 2 *1/2* years before a decision. Congress could consider several ways to speed up enforcement of patent infringement statutes. It might designate special judges for patent cases, or increase judicial manpower devoted to hearing patent cases. In a way, there is already extrajudicial manpower available; the International Trade Commission employs four administrative law judges to hear cases under Section 337 of the Tariff Act of 1930. Under section 337, a U.S. firm whose patent is infringed by imported goods can apply for an order to stop the goods from entering the country. The procedures for hearing and settling cases brought under Section 337 have been found to violate GATT, however, and the Administration is considering how to amend Section 337 to satisfy GATT while keeping its advantages of a quick trial and enforcement at the border.

Effective domestic intellectual property protection is not sufficient, however. U.S. firms need adequate protection in foreign markets as well. To many innovative companies, the Japanese patent system is a particular problem. It is slower than ours in issuing and enforcing patents, and it strongly favors licensing of patents-something U.S. firms do not always wish to do. The Administration is pursuing negotiations to fix these problems. Another problem for American firms is that they don't understand the Japanese system very well, and can't easily find out more. The language barrier adds to the difficulties. Congress might wish to establish a program in the U.S. Patent and Trademark Office to collect and disseminate information about the Japanese system.

Differing patent systems throughout the world present a general problem. Usually, a firm must

apply for a patent in each country in which it wants protection; this is expensive and time-consuming. One option is to harmonize international patent law and application procedures, at least among nations that trade heavily in high-technology products. The United States has been negotiating with Japan and the countries of the European Community to this end. Any agreement will probably require substantial changes in the U.S. patent system. While such changes--e.g., changing to a first-to-file system rather than first-to-invent-will be controversial, Congress might give any such proposal serious consideration, since a harmonized (and eventually unified) system could take much of the time and expense out of obtaining international patent protection.

Strategic *Technology Policy*

With few exceptions, the U.S. Government has been reluctant to adopt proactive policies to build competitiveness. For generations, most American academics and policymakers have been convinced that market mechanisms were better than government planners at identifying promising technologies. There are examples of failures of central planning that reinforce these beliefs, and for several decades, the economic performance of the American economy also justified that faith.

There are reasons to challenge this ideology now. First is the simple fact that many American industries are having great trouble in world competition, and some of the ablest international competitors assuredly do not have freer markets or lighter government involvement in supporting industrial technologies than the United States does. The governments of many European nations, Japan, Korea, and Taiwan, have all actively promoted manufacturing technology acquisition, development, and diffusion; and while they have had their failures, they have had many outstanding successes. This is not proof, of course. Many other nations with less than admirable economic performance have also supported technology development and diffusion.

America's own history provides examples of successful commercial industries building on abundant government support of technology. Some of this has been an indirect effect; the Department of Defense's support of the early development of semiconductors and computers paved the way for substantial investments in commercial technologies by the private sector. But the United States has sometimes been willing to make exceptions to the tenet that direct government support should be limit mostly to basic research and national security. The development of a U.S. civilian aircraft industry can be linked directly to government-supported research on airframe and propulsion technologies in the early part of the century. This support was justified on patriotic grounds, and was not drawn so narrowly as to include only military security needs. Government support of agricultural technology through the land grant universities and the Cooperative Extension Service has been a key to the rapid productivity growth of American agriculture in the 20th century. Government support of the space program from the 1950s onward rested as much on national pride as on defense needs, and has had some important commercial payoffs.

Still, the argument most often put forward for Federal support of technology development remains rooted in national security. The Department of Defense depends on the civilian microelectronics and other high technology industries of its procurement needs. This was a key factor in the consideration of whether and how much to support Sematech, high-temperature superconductivity, and lately, high-definition television. But the idea that only the direct, immediate needs of the military justify government support of technology development is wearing thin. The time is ripe for reopening the question of how the Federal government could support development of civilian industrial technology proactively—i.e., before the industry is so weakened that national security is threatened.

Many people still reject this strategy. They argue that selective government support of key technologies or industrial sectors amounts to

"picking winners" and that government bureaucrats are ill-equipped to make these choices. This argument rests mostly on politics. The American political system is too subject to manipulation by special interests, it is argued, to make rational choices among all the potential industries and technologies that might merit government support. This is a forceful argument, one to be taken seriously. Another pillar of the argument is the simple claim that the market, with its imperfections, is better than government interference.

The other side has a powerful justification as well. That is, that some technologies are so risky or involve such large investments over the long term that little or no development will be undertaken unless society, which stands to benefit, shares the risk of development. In the U.S. financial environment, with its burdensome penalties on long-term investment, the argument takes on special force.

The debate over "picking winners" has resolved little. Those who argue that government cannot make consistently rational choices can point to failures, such as the money poured into the Synfuels Corporation in the early 1980s to make wood-based, coal-based, and shale-based substitutes for petroleum. Japanese policies have not been invariably successful either. Examples of projects that did not achieve their initial objectives include efforts to jump-start biotechnology development, the fifth-generation computer project, and entry in the civilian air transport industry.

There have been some notable successes as well. U.S. Government support for aircraft technology development, through both civilian and military agencies, and agriculture are examples. These industries, which have had much greater government support than most, are advanced technologically and successful internationally. Both can boast large trade surpluses. Successes in Japan encompass the major industries on which that nation's astounding postwar economic achievements rest—first, steel, chemicals, and shipbuilding; then automobiles; and now microelectronics, computers, and telecommunications.

More to the point, the argument cannot (and should not) be resolved by counting up successes and failures. Any sustained effort to support new technology development will include some failures, and some industries might succeed more in spite of government support than because of it. The fact is, the U.S. Government is increasingly being asked to support technology development, and it is becoming ever more obvious that the reason is to build civilian industrial competitiveness. It is possible to take the best from the "picking winners' debate by focusing on how to design institutions that are open to counsel from and collaboration with industry and other interests, but avoid becoming their captives. Another lesson is that a crisis is a poor crucible for making such decisions. The failure of the Synfuels project can be traced largely to the atmosphere of crisis in which it was born.

A Civilian Technology Agency

Efforts to support industrial technology will require commitment and money. Both have their limits. Public initiatives to help private manufacturing improve its performance cannot afford to plunge into repairing and developing every industry and technology. Yet the Federal Government has no institutional ability to discriminate between technologies and industries that are most promising for the Nation's economic future, and those that have some appeal but are less important. While the U.S. Government has acted to support certain key technologies, the responses to declining competitiveness have been ad hoc, and are usually justified by the seriousness of potential losses in military security. If Congress wishes to consider ways of responding to pleas for support of technology toward the goal of economic security, one option is to create a civilian technology agency.

One approach is to build on existing institutions. NIST's Advanced Technology Program, created in the 1988 trade act and funded for the

first time in fiscal year 1990, at $10 million has the potential to develop into a CTA. A bill that passed the Senate in 1989 authorized $100 million for the program to support industry-led joint R&D in economically critical technologies. Five such technologies were spelled out in the Act.

Other bills in both the 100th and the 101st Congress proposed the creation of a Civilian Technology Agency (CTA) within a new Department of Industry and Technology taking the place of the Department of Commerce. The agency would make grants or cooperative agreements with private performers of R&D on high-risk projects that could have exceptional value to the civilian economy. The closest analogy among existing agencies to a CTA is the Defense Advanced Research Projects Agency, or DARPA, which supports development in technologies and industries considered critical to the nation's defense. This small agency (staff of 150, funding of nearly $2 billion per year) has gained a reputation for placing intelligent bets in serving U.S. military technology needs. It makes long-term commitments that have added up to decades for some of its projects. DARPA has at times interpreted its mission broadly, supporting technology development that will benefit the commercial sector because the military depends on that sector. A CTA could learn a good deal from DARPA's experience on how to evaluate the potential benefits and risks of investments in new technology, and how to balance the pressures of industrial and parochial interests in making such decisions. The CTA might be subject to greater special-interest pressures, but the difference is likely to be one of degree rather than kind.

In some ways, a CTA would be quite different from DARPA. Most important, a CTA would interact closely with industry in choosing what technologies to support and designing the R&D projects. Until recently, DARPA did not fund projects jointly with industry; a CTA would probably finance most of its projects with contributions from industry that are at least equal to if not greater than the government share. This joint funding is essential as assurance that industry is genuinely committed that and the projects are really promising commercially, in the opinion of industry. Thus, the problem of government's "picking winners" would be greatly diminished.

Where in the Federal bureaucracy the CTA is placed may not matter very much. There are some advantages to its being an independent agency like the National Science Foundation. With the right mandate, independent agencies, even small ones, can wield influence beyond what their size would indicate. (NSF is funded at less than $2 billion per year.) However, DARPA demonstrates that a small agency within an enormous bureaucracy can be effective and powerful. With the right design, sufficient funds, top-notch staff, and a strong mandate from Congress, a CTA could probably function well either within the Department of Commerce (or a successor department) or independently.

Other issues are more important to a CTA's performance. Judging by the difference between DARPA's performance and the record of other DoD technology development and acquisition, it is clear that the agency should not be constrained by detailed rules and procedures. Giving the agency staff a large degree of freedom and responsibility could help to attract and keep technically first-rate people, which is increasingly difficult as salaries for scientists and engineers rise faster than government salaries.

One of CTA's first tasks would be to develop guidelines for the selection of industries or technologies to consider for support. Here, much can be learned from the debates over whether to support specific technologies or projects like HDTV, superconductivity, and Sematech. There is an obvious preference for industries that are high-tech, provide well-paid jobs, and have high growth potential. In addition, CTA would need to consider entire technological systems, not just particular technologies. For example, if it chose some semiconductor

technologies, it would have to be sensitive to R&D needs throughout the system, starting with improved materials, and continuing through things like lithography for etching chips, automated techniques for packaging, and soon. CTA could also look for technologies important to more than one application or industry downstream.

One of the surest ways to doom the effort would be to subject a CTA to unrealistic expectations. If CTA is expected to make strategic choices of high-risk technologies, it would have to be given time for its investments to play out, and some leeway to make less than perfect choices. The ability to make multi-year funding could also be critical. As it is, American business regards government support as volatile and undependable. The fact that Silicon Valley companies took very seriously recent rumors that the Administration proposed to abandon funding for Sematech illustrates the point. If the agency is to succeed at pushing technology, it would need to provide steady support for several years to many different technologies. Even then, it should not be expected to turn American industrial competitiveness around singlehandedly. Coordinated support in other policy areas like trade and macroeconomic policy will be needed to do that.

Chapter 2

Strategies To Improve US. Manufacturing Technology: Policy Issues and Options

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Chapter 2

Strategies To Improve U.S. Manufacturing Technology: Policy Issues and Options

Only 5 years ago, the idea that American manufacturing was in trouble was not widely accepted. Many people-including manufacturers themselves—blamed the spiraling trade deficits on nothing more than the overvalued dollar and unfair trading practices by other nations. As the 1990s begin, a soberer view has taken over. Yes, the high dollar did interfere with U.S. exports. Five years after the dollar started down, the merchandise trade deficit had dropped one-third from its peak and exports were at anew high. But the deficit was still running at over $100 billion a year and 2.1 percent of GNP in 1989, and that is still very high by historical standards; moreover, the dollar had started climbing again. And yes, many of our trading partners, including some of the richest, discriminate subtly or openly against imports. Nevertheless, the Japanese are beating us in our own home market in things like autos and semiconductors, where not so long ago we were the world's best; the Koreans and Taiwanese have become adept competitors in some kinds of semiconductors and computers; and the European success with the Airbus threatens our top remaining export industry.

Today, there is much greater agreement that U.S. manufacturing has to improve to keep up with the competition, and that technology is key to the improvement. It is not so clear that, as a nation, we are ready to make the commitment-or the sacrifices—that are required to reinvigorate U.S. manufacturing. Much of the effort has to come from inside industry, with better management and better relations between managers and workers. But some involves all of us, as savers and consumers, teachers and students and families of students, taxpayers and citizens.

For example, a major reason for the notorious shortsightedness of American industry is high interest rates. The high cost of capital discourages investment in new plant and equipment, and has an even more dampening effect on research and development, with its more distant and uncertain payoff. The massive U.S. Government budget deficits of the 1980s, combined with low personal savings rates, are prime reasons for high interest rates. So far, there is little sign that either political leaders or voters are ready to make the disagreeable choices—higher taxes or cuts in popular government programs or both-that would make a real dent in the budget deficit.

Despite the decline in real wages and stagnation in family income over the past decade, Americans are still the richest people in the world; only Canada rivals the United States in income per capita.[1] We got a free ride in rising consumption throughout the 1980s because foreign investors remained willing to finance our budget and merchandise trade deficits. And rising consumption led a record peacetime expansion of the economy. It is a real question whether such a nation-still comfortable, not really hurting--can summon the energies needed to regain technological leadership in an increasingly competitive world.

Traditionally, U.S. Government policy on technology for manufacturing has been to support basic research, allowing private companies to help themselves to whatever items of commercial interest come out of that research. Federal R&D aimed at applications has mostly been limited to defense and space (areas in which the government itself is customer), health, energy (mainly nuclear), and agriculture. On occasion in the past, Department of Defense spending for both R&D and procurement has given commercial industries a vital boost, in such things as semiconductors, computers, and aircraft. But these spinoffs are less common than they used to be. Military systems have become more esoteric and more are secret; differing business practices in the military and civilian sectors erect barriers to the transfer of technology; the processes for manufacturing a few copies of a custom item (for the military) has little in common with high-volume low-cost manufacture (for commercial markets);

[1]Figure 1-3 shows gross domestic product per capita for the United States and other countries. in the United States, from 1977 to 1988, the average family income was virtually unchanged in constant dollars. However, there were marked changes in distribution; in every income decile up through the eighth, family income declined over the 12 years, and the lower the income the greater the decline. Only in the top decile was there a significant increase in family income (16 percent), and the top 1 percent racked up an increase of 49 percent. (U.S. Congress, Congressional Budget Office, *The Changing Distribution of Federal Taxes: 1975-1990* (Washington, DC: Congressional Budget Office, 1987), p. 39.

and in many high-technology areas, the defense sector is lagging behind the commercial.[2] Today, if the government wants to support industry in commercializing new technologies, it must usually do so more directly.

Some changes are occurring. Recently, the U.S. Government has shown increased interest in positive actions to help American industry restore its technological edge. Part of the reason is defense-related. Loss of competitiveness in the commercial sector (especially in semiconductors) is a worry to the defense establishment, because it means that weapons systems may either have to rely on foreign suppliers or else take second best.[3] More broadly, the idea that economic performance is at least as important to the United States as military security has gained some ground.

Congress has taken several initiatives to offer more government support for improving U.S. manufacturing performance. Legislation passed in the 1980s promotes technology transfer from the Federal laboratories. In the 1988 trade act, Congress created regional centers to transfer advanced manufacturing technology to industry. It has appropriated special funds to advance R&D in high-temperature superconductivity. In a distinct departure from traditional U.S. policy, it is providing $100 million a year for 5 years to Sematech, the government-industry consortium for R&D in semiconductor manufacturing technology. New ideas for a more aggressive, commercially oriented technology policy are getting an attentive hearing in Congress.

Real change in this direction is by no means certain, however. According to press reports in late 1989, the Administration was ready to rein in any DoD support for technologies that are not strictly military, and continued funding for Sematech was in question.[4] Responding to protests from Congress, the Administration denied the reports, but also took pains to announce opposition to any increased funding for Sematech or similar ventures.

The government programs actually undertaken so far to improve technology in manufacturing have been modest, and spending for them is low (Sematech's $100 million a year is by far the most expensive of the new initiatives). The costs could rise considerably if the government sticks with the programs already started, and possibly enlarges them as it gains experience. Still more costly would be real efforts to change some of the basic factors affecting U.S. competitiveness-getting the cost of capital down, doing afar better job of educating and training the work force.

As the arms race with the Soviet Union dwindles, the prospects are good for reducing military spending. Some of those savings could go for deficit reduction, or for measures to improve education and training, or for technology advance and diffusion. Some might go for other social purposes. On the other hand, the savings might be spent on further lowering of taxes and the resulting increase in private consumption. These are public policy choices. National leaders, guided by the voters, will ultimately make them.

Quite a few government actions are worth considering as ways to promote a stronger technological base for American manufacturing, some of them traditional and others with little precedent in this country. These actions can be directed toward four somewhat overlapping strategic targets.

- Financial Policies. These shape the financial environment for industry, including the cost of capital. The broadest of these policies--on taxes, spending, and the Federal budget—affect the whole sweep of the economy and are subjects of intense national debate; they are discussed in general terms in this report. Closer attention is given to specific policies that might help firms take a longer term view than quarterly profit performance and invest more heavily in technology development and up-to-date production equipment.

[2] U.S. Congress, Office of Technology Assessment, *Commercializing High-Temperature Superconductivity, OTA-~-388* (Springfield, VA: *National* Technical Information Service, 1988), pp. 94-98; and *Holding the Edge:* Maintaining *the Defense Technology Base,* OTA-ISC-420 (Washington, DC: U.S. Government Printing Office, 1989), passim and esp. pp. 174-178.

[3] U.S. Department of Defense, 'Bolstering Defense Industrial Competitiveness," report to the Secretary of Defense by the Under Secretary of Defense for Acquisition, July 1988; Defense Science Board, ''Report of the Defense Science Board Task Force on Defense Semiconductor Dependency, ' report to the Office of the Under Secretary of Defense for Acquisition, February *1987;* U.S. Congress, Office of Technology Assessment, *Holding the Edge,* op. cit.

[4] *New Technology Week, Nov.* 6, 1989.

- Human Resource Policies. These affect the availability of well-qualified people to fill manufacturing jobs, and thus have a powerful influence on competitiveness. Education of the Nation's children and the reeducation and training of adult workers are subjects too broad to fit completely within a report on manufacturing technology, but some policies with special relevance to manufacturing performance are selected for consideration.
- Technology Diffusion Policies. These are positive, deliberate government actions to help firms improve their manufacturing processes and commercialize new or improved products. They support technological advance across the board for all manufacturers, with no distinction in kind (i.e., no special support for particular technologies or industries). Congress has already taken a few steps in this direction. Further options include such measures as easier access to new technologies coming out of Federal labs and stepped-up Federal support for technology extension services to manufacturers.
- Strategic Technology Policy. This includes a coherent set of actions that would promote general technology advance and also target support to technologies that are seen as vital to economic growth. The U.S. Government has used some of the tools of strategic technology policy in the past, sometimes quite successfully, but usually in an ad hoc way. Current examples include the Federal funding for Sematech and the special collaborations on high-temperature superconductivity R&D in three national labs. If a consensus develops in favor of forming a coherent strategic technology policy, an agency or institution would need to be in charge, to define goals and choose technologies for government backing that fit the goals.

This list does not by any means exhaust the possibilities for government actions to bolster the competitiveness of manufacturing. Many nations have used broader instruments of policy than these to promote industries they consider essential to their countries' well-being. Japan, other East Asian nations and, increasingly, the European Community have used a full range of technology, industry and trade policies in support of the strategic industries they wish to develop. Policy tools include such things as preferential low-cost loans, government-guaranteed purchases, and trade protection against powerful foreign competitors during the infancy and development of native industries.

Improving the financial environment and upgrading education and training are the fundamentals for any set of policies to improve technology. It may be, however, that the addition of policies to step up technology diffusion and target government R&D support to critical commercial technologies will not go far enough to boost American manufacturing to world class competitive level, when other nations are doing much more. Whether the United States can or should employ more comprehensive policies to bolster competitiveness is an open question, only touched on in this report. Industry and trade policies of the Asian rim nations and the European community, and their possible relevance to U.S. policy, will be considered in the final report of OTA's assessment of Technology, Innovation, and U.S. Trade.

FINANCING LONG-TERM INVESTMENT

American business managers have been less willing than their Japanese and German competitors to make investments in technology development or equipment that requires many years to begin yielding a return. Paying attention to the bottom line in the short term is obviously important, but too much of it can be costly in a world where manufacturers in other developed nations pay less attention to short-term profit and more to long-term growth and market share.

American shortsightedness will be hard to overcome. If it were mostly due to culture—the way managers and decisionmakers are socialized and taught to think about problems—some good might be accomplished by progressive business schools revamping their curricula. Also, if the problem were merely cultural, experience would prove that managers who concentrate on long-term gain outperform those who do not, and the problem would be self-correcting. But the myopia is long-standing; experience has not remedied it. And our best business schools have led-not resisted—the effort to analyze and propose solutions to the shortsightedness of American management. Undoubtedly, some cultural changes are needed, but without changes in the underlying financial environment, simply enlightening managers on the potential gains of longer term vision probably will have little effect.

The underlying financial environment that makes our undue emphasis on short-term profit a consistently rational choice for American managers consists of many parts. The most straightforward is the cost of capital: even in the absence of other factors, the fact that American manufacturers have faced consistently higher capital costs than their Japanese and West German competitors will shorten the required payback period for American investments.[5] Another factor is the relationship between providers of capital and companies. Providers of both debt and equity capital have pushed American corporations to pay more attention to short term gains than to long term market share. Japanese and West German banks and other creditors and equityholders have more incentives to focus on long-term growth rather than short-term payout. American managers, particularly those most responsible for strategic decisions, may also be encouraged personally to focus on short-term profit. According to the MIT Commission on Industrial Productivity, there is 'no shortage of executive bonuses geared to yearly or even semiannual performance."[6] Finally, the uncertainty of the business environment could also lead managers to be cautious about long-term investments. Analysts point to uncertainties such as money exchange rates, regulatory and fiscal policies, and trade.[7] These factors all play some role in how managers view long-term investment. Making significant changes in any of them will be difficult, even where they are sensitive to Federal policy intervention.

Capital Costs

Our ablest international competitors have made arrangements to provide capital to industry on more favorable terms than the market provides. So, however, have a number of Third World countries that are regarded as prime examples of the pitfalls of bungled, state-led planning. Even in cases where channeling of capital has rather clearly promoted industrial development—Japan is most often cited—the policy involved a heavy price to consumers. If Congress wishes to overcome the disadvantage of our capital costs, it should be known at the outset that this cannot be done without sacrifice.

There are two basic approaches to the problem. One is to make capital more available to everyone; the other is to use selective policies to reduce its costs for certain sectors or activities. The first approach is to increase the pool of savings from which capital is formed. This includes increasing government saving, which means reducing the Federal budget deficit in one way or another (raising revenues or cutting spending). The second approach involves the use of tax instruments to reduce the cost of capital investment, R&D, and other productivity-enhancing activities.

The obvious step is to reduce or eliminate the Federal budget deficit. The tax cuts and increased government spending of the 1980s were an enormous fiscal stimulus to the American economy. To avoid excessive inflation, the Federal Reserve has pursued a very tight monetary policy. This, in turn, keeps upward pressure on interest rates, which does help control inflation but also gradually robs industries of the capital they need to improve real wages and productivity.[8] The alternative—a less restrictive monetary policy—would not drive interest rates up so high in the short run, but the resulting inflation could result in disaster too. With high inflation and lower interest rates, foreign investors who are now financing a large share of American investment could find investments here less attractive and might even lose confidence in the soundness of investments in the United States, which could result in a severe recession. Charles Schultze characterizes this scenario-which he thinks unlikely to happen—as ''the wolf at the door. Most experts agree that it is impossible to eliminate the budget deficit rapidly, that is, in a couple of years, but that some combination of higher revenue and lower spending over a decade or so will be needed. Lest we forget, it was a combination of lower taxes (revenue) and greater

[5]Robert N. McCauley and Steven A Zimmer, "Explaining International Differences in the Cost of Capital," *Federal Reserve Bank of New York Quarterly Review,* summer 1989, pp. 7-28.

[6]Michael L. Dertouzos, Richard K, Lester, and Robert M. Solow, *Made in America: Regaining the Productive Edge* (Cambridge, MA: The MIT Press, 1989), p. 62.

[7]Ibid., p, 61.

[8]This argument is set out in Charles L. Schultze, "Of Wolves, Termites and Pussycats: Or, Why We Should Worry About the Budget Deficit," *The Brookings Review,* summer 1989, pp. 26-33.

[9]Ibid., p. 26.

Federal spending in the 1980s that caused the Federal budget deficit to balloon after 1981.

Encouraging Savings

Saving is the source of capital. At any given level of demand for capital, if domestic savings rates fall, capital formation must fall unless foreign sources make up the difference. Some dependence on foreign capital is probably acceptable for any nation, but excessive reliance on it is worrisome. American savings rates have fallen in the 1980s, partly because the budget deficit comprises a large chunk of dissaving, but also partly because household and business savings rates have dropped.

Of the two, the drop in household savings is much greater,. Household savings averaged nearly 8 percent of GNP over the 1970s, and dropped to 2.1 percent by the mid-1980s, partially recovering thereafter, to about 5 percent by the end of the decade. To raise the household savings rate, Congress could consider incentives to save, such as preferential tax treatment of interest income or deferred taxation on income that is saved. The latter has been tried in the form of deferred tax on money placed in Individual Retirement Accounts (IRAs), with disappointing results. The fact that the household savings rate fell while IRA tax incentives were in place led many economists to conclude that savings incentives by themselves are ineffective, and that discouraging consumption must be a part of any package to increase private savings rates. This is not a universally accepted conclusion, however. For example, Hatsopoulos, Krugman and Poterba argue that a national savings initiative that would encourage savings in all tax brackets and reward regular savings rather than portfolio reshuffling could be effective.[10] Congress could consider a national savings initiative, based on these principles and accompanied by a public campaign to encourage savings, as was done in Japan after World War II. Before the war, Japanese household savings rates were lower than American rates.

Clearly, Japan's savings rates were a response to much more than just a national savings initiative, and it may well be that even heavy incentives and a public campaign are not enough to raise savings to the levels needed to sustain competitiveness (i.e., above the rates of the 1970s and 1960s). Americans have been encouraged in various ways to consume, and consumption reached all-time highs as a percent of GNP in the 1980s. Congress may also wish to consider some measures to discourage consumption.[11] The classic device is the consumption tax, which has been rejected before because of its regressivity.[12] However, by scaling consumption taxes to tax most lightly (or not at all) those items regarded as necessities and most heavily those considered luxuries, several European countries have shown that consumption taxes are not necessarily overly regressive.

Another option might be additional limitations on consumers' ability to deduct mortgage interest payments. Mortgage interest payments are 100 percent deductible up to the generous limit of two homes (primary and secondary). Because of this deductibility, and because Americans are allowed to make relatively low downpayments, Americans consume more housing and save less than people in Japan, Germany, and many other advanced nations. While home equity is a form of savings for a household, the money tied up in housing is not the same as savings accounts and other forms of savings from society's point of view, because of its illiquidity. It is again to the household, but not available for other investments. Moreover, the buildup of home equity may substitute for other kinds of savings for many households. Limiting mortgage interest deductibility to one home could also help to raise household savings rates. In fact, the current limits may be doing so. While the deductions allowed on mortgage interest payments are still substantial, they

10George N. Hatsopoulos, Paul R. Krugman, and James M. Poterba, *Overconsumption: The Challenge to U.S. Economic Policy* (Washington, DC: American Business Conference and Thermo Electron Corp., 1989), p. 14.

11Some steps have been taken. In the 1986 tax act, Congress began to phase out the deductibility of interest on many types of consumer credit—in 1990, 10 percent of consumer interest paid can be deducted, and none after that-and placed additional (though not very restrictive) limits on mortgage interest deductibility. These had little effect on the propensity to consume, however, because consumers can still deduct substantial amounts of interest on home equity loans, which have substituted to some extent for other types of consumer credit. Indeed, as consumer interest deductibility has diminished, the value of home equity lines of credit has mushroomed. In 1986, the year of the Tax Reform Act, home equity loans totaled $35 billion; by 1989, the total was $100 billion, Source: David Olson, SMR Research, personal communication, January 1989.

12p example, the late Joseph Pechman, a Prominent tax expert at The Brookings Institution, maintained that consumption trees would favor the wealthy, and argued for a more progressive income tax. See Hobart Rowen, ''Joseph Pechman's Simple Solution for Fairer Taxes, ' *The Washington Post, Dec. 31,1989.*

are more limited than they were. This may be one cause of the partial recovery of personal saving from its nadir of 1987, and the slowdown in the rate of growth of housing prices.

Selective Lowering of Capital Costs

Progress in budget-balancing and stimulating saving would result in moderation of interest rates and encourage more longer term investment. That may not be enough to support the kind of change needed to reverse the relative slide of American manufacturing technology and productivity. After all, before the run-up of interest rates brought on by the burgeoning deficit, American manufacturing productivity was still advancing at a slow pace, compared with its earlier performance and compared with Japan. Congress might wish to consider other measures to lower the cost of investment for specific sectors or purposes.

The United States has tried using tax instruments to stimulate additional investment in technology development and application in the private sector. These measures include accelerated depreciation allowances and tax credits or deductions for the purchase of equipment and facilities, and research and development tax credits. Different policies affect different activities in the spectrum of technology development, implementation, and diffusion. The rationale behind all of these measures is that the market does not provide strong enough incentives to invest in the supported activities, considering the total of private and social benefits that stem from investments in plant and equipment or research and development.

Right now, the case for underinvestment in equipment-particularly advanced equipment to produce state-of-the-art products--probably is stronger than arguments that we have underinvested in R&D. However, both Japan and West Germany spend a higher percentage of their GNP on civilian R&D,[13] and the European Community is topping that off with about $1.5 billion a year on R&D through the Framework program.[14] Most of the R&D performed by these key competitors is dedicated to improving civilian science and technology. The United States spends more money on R&D, but much of it is geared towards military technologies. About half the total R&D spending in the United States is funded by the Federal Government, and 70 percent of that by DoD. In contrast, less than 5 percent of Japan's government R&D is spent on defense, and about 12 percent of West Germany's.[15] While lagging R&D spending has not been a major competitive problem for American industry in the past, it is becoming one.

Capital investment is probably a greater problem at the moment. Particularly in high-technology industries, capital equipment investment is a key part of technical competitiveness, and America's high capital costs have damped investment. If Congress wishes to provide incentives to stimulate the development, commercialization, and implementation of new technology, it might consider reauthorizing some form of rapid depreciation or investment tax credit, both of which were eliminated in the 1986 Tax Reform Act.

Both accelerated depreciation and investment tax credits (ITC) can be aimed at encouraging businesses to acquire new capital equipment. Investment tax credits have been applied, on and off, since the early 1960s, most recently in the Economic Recovery Tax Act of 1981. This tax credit was eliminated in 1986, in favor of an overall reduction in the corporate tax rate. The Accelerated Cost Recovery System (ACRS) was also eliminated (although certain classes of assets still enjoy fast depreciation).

Some argue that the ITC and ACRS were inappropriate in the frost place—that because a firm can reap all (or nearly all) the benefit of investing in new capital equipment, it is inappropriate for society to subsidize such purchases. It is also unclear how effective the subsidy was, at least in the 1980s, at stimulating capital investment. according to various estimates, for every dollar of revenue the Treasury foregoes as a result of the investment tax credit,

[13]By 1985, Japan's *total* R&D spending was slightly above U.S. total R&D spending by 0.1 percent of GNP, according to a preliminary figure from the National Science Foundation. See National Science Foundation, *International Science and Technology Data Update* 1987, NSF 87-319 (Washington, DC: 1987).

[14]The EC contributes about 5 percent of all government-funded R&D in the countries of the European Community.

[15]NSF, op. cit., p. 9.

industry invests $0.12 to $0.80 in equipment, above what would have been invested without the credit.[16]

Despite the apparently modest results of the ITC, there are arguments in favor of tax stimuli for investment. Investment in durable equipment was robust in the recovery from the 1982 recession, even though real interest rates were high, so without the ITC investment might have been smaller than it was. If the intent of the ITC was to stimulate equipment purchases to raise productivity, that, too, could be claimed as a modest success. Productivity growth in American manufacturing averaged 3.5 percent annually from 1979 to 1986, a substantial pickup from its 1.4 percent average annual increase in 1973-79, and even higher than the 3.2 percent annual average of 1960-73, the heyday of American manufacturing. To what extent this is causally related to investment incentives in the 1980s is not known. For example, some of the productivity growth of the period came from the closure of inefficient plants, rather than from new investments in plant and equipment. However, the coincidence of high productivity growth and investment stimulation is worth examination.

The effect of investment tax incentives on productivity improvement and the diffusion of best practice in American manufacturing will require additional analysis. Congress may wish to initiate such a study in one of its analytical agencies, or by a panel of experts. This is a topic of great importance, but considerable uncertainty. Some analysis suggests that investment tax incentives are inefficient, and they are certainly expensive. Between 1979 and 1987, the ITC cost between $13 billion and $37 billion each year in tax expenditure; ACRS' cost varied from $8 billion in 1982 to $64 billion at its peak in 1987.[17] Unless Congress can find another way to raise revenue, or effect other substantial spending cuts, reinstating investment tax incentives will only worsen the deficit and increase the pressure to keep interest rates up. Yet in view of the pressing importance of raising productivity and diffusing state-of-the-art technology in manufacturing, these tax changes deserve consideration.

R&D tax credits are less controversial, at least in principle, and are a great deal less expensive. It is widely agreed that there are many societal benefits from the generation of new knowledge that individual firms cannot capture. As for the cost, in 1985, before the provision for R&D tax credits in Economic Recovery Tax Act (ERTA) and Tax Equity and Fiscal Reform Act expired and before the new tax law, the tax revenues foregone because of the R&D tax credit were estimated at $700 million by the Joint Committee on Taxation.[18] Estimates of the amount of additional R&D generated by each dollar of foregone revenue range from $0.35 and $0.99.[19] The high estimate, if correct, indicates that the R&D tax credit is quite efficient, compared with many other tax instruments; but if the low estimate is correct, the impact is modest.

One possible explanation for a moderate impact at the low range of estimates is that the tax credit for R&D is only one stimulus. R&D costs can be expensed--educted from revenues to yield taxable income—in the year they are incurred, which is the ultimate in fast depreciation. While the R&D tax credit has repeatedly been subject to sunset provisions, expensing has been an option for decades. With a powerful stimulus already in place, we would expect the additional impact of a tax credit to be modest. Also, it is possible that the impact of the R&D tax credit in the early 1980s was affected by the ITC and ACRS, which made other competing investments more attractive.

The R&D tax credit survived the Tax Reform Act of 1986, but in a form that many agree is not as effective as it could be. One often-mentioned criticism is that the R&D tax credit has never been

16Joseph J. Cordes, ''The Effect of Tax Policy on the Creation of New Technical Knowledge: An Assessment of the Evidence, ' in Richard M Cyert &David C. Mowery (eds.) *The impact of Technological Change on Employment and Economic Growth* (Cambridge, MA: Ballinger, 1988), and Robert Chirinko and Robert Eisner, "Tax Policy and Investment in Major U.S. Macroeconomic Models, " *Journal of Public Economics,* March 1983. These estimates were developed using econometric simulations, and varying assumptions in the simulations account for the large range of the estimates.

17Joint Committee on Taxation, *Estimates of Federal Tax Expenditures*, Fiscal Years, Annual.

18U.S. Congress, Congressional Budget office, *Federal Support for R&D and Innovation* (Washington, DC: Congressional Budget Office, April 1984).

19Ibid., p. 78. Both the R&D tax credit and the investment tax credit were designed to elicit additional spending on R&D and investment. While the R&D tax credit was designed to apply only to incremental spending above a base level, there is little doubt that some of the credit was claimed for R&D that would have been done anyway by companies increasing R&D; and many assert that corporations redefine certain activities as R&D in order to claim the credit. These are some of the considerations that are taken into account when estimating how much additional R&D was done as a result solely of the tax credit.

made permanent, and it is therefore not something business planners can count on. While there has been no lapse in its availability, the form of the tax credit has been changed twice since it was enacted in the ERTA in 1981. It was reauthorized in the Omnibus Budget Reconciliation Act of 1989, with a few changes.[20] So, while some analysts have pointed out that R&D tax credits have not clearly stimulated significant increases in R&D spending, uncertainty over the form and duration of the credit itself maybe partially responsible. Congress might wish to consider making the tax credit permanent.

When investment and R&D tax credits are subjected to tests of efficiency or effectiveness, both seem to have only a modest impact.[21] While analysis of the effects of such measures can give some insight, it is impossible to predict accurately the responses of business to these stimuli to develop new technology or diffuse best practice. Although a few different combinations of stimuli have been tried a few times, the possibilities of these measures have not been exhausted. Meanwhile, there is strong evidence that something is needed to stimulate technology development and diffusion. Under these uncertainties, it may be tempting to try something small or temporary, as the R&D tax credit has always been in the past, and as the ITC proved to be. If the tools are used tentatively, however, modest impacts should be expected. We may have to rely more on informed judgment than economic analysis, and make a stronger commitment to tax or other stimuli to investment and R&D.

Relationships With Providers of Capital

In addition to high capital costs, there are other pressures in the American financial environment to focus on short-term gain and avoid long-term or risky investments. Heavy turnover of stock in market trading and the pressures on institutional money mangers to show short-term gains in excess of market averages are important factors affecting the outlook of publicly owned American companies. In Japan, these problems have been avoided through stable (or mutual) shareholding, an arrangement which permits a company to cache most of its stock--estimates of 70 percent are common-in the hands of other companies, where it is not often sold or traded, and there is little pressure to pay large dividends.[22] While Japan had a long tradition of mutual shareholding within its prewar *zaibatsu* and postwar *keiretsu* company groups, incentives to find stable shareholders were increased in the early 1970s when government agencies began to worry that Japan's heavy dependence on outside expertise was bringing with it too much foreign investment. The renewed zeal with which company managers sought stable shareholders, then, was a response to the threat of foreign takeovers.[23]

If Japanese companies can afford to treat their shareholders as peripheral to the decisionmaking process, American companies have come under increasing pressure to do just the opposite. American firms have *always* had to pay more attention to the demands of their shareholders than Japanese firms. However, recently, the demands of shareholders have focused more than ever on short-term gains, and as a consequence American fins' concern with short-term performance has become a preoccupation.

The change has come about in part because of the wave of merger and acquisition (M&A) activity in the 1980s. Mergers and acquisitions go on constantly, occasionally rising to peaks; however, the activity seen at peak periods differs in kind as well as magnitude from ordinary M&A. In the 1980s, the difference was that far more institutions and individuals could become acquirers, even with relatively small resources. In the past, M&A was characterized by large firms acquiring-in friendly or hostile fashion-smaller ones. The change resulted from relatively loose antitrust law enforcement, and the availability of short-term, high-interest capital from

specifically, the credit now applies to R&D spending over a fixed base, which is calculated as the ratio of a firm's R&D expenses to gross receipts from 1984 to 1988. In addition, the new law allows firms to claim R&D on prospective lines of business, rather than limiting qualified credits to R&D in current lines as the old law did. Source: David L. Brumbaugh, "The Research and Experimentation Tax Credit,' CRS Issue Brief, updated Dec. 21, 1989.

21The h@ estimates of additional expenditure caused by the ITC and the R&D tax credit show that both could also be regarded as quite effective, but most analysts seem to think that the true impact is well below the high end.

22See, for example, Hideo Ishihara, ''Japan's Compliant Shareholders, " *The Asian Wall Street Journal Weekly*, June 13, 1988; "Back of the Queue, Please," *The Economist*, Apr. 29, 1989; Robert J. Ballon and Iwao Tomita, *The Financial Behavior of Japanese Colorations* (Tokyo: Kodansha International, 1988), pp. 50-53.

23Ballon and Tomita, op. Cit., pp. 50-51.

high-risk bonds ("junk" bonds) for financing. Finally, another characteristic of the 1980s peak was the rise of the bustup takeover, where the acquirer quickly split up the acquired company and sold many of its pieces in order to reduce the debt incurred in the takeover.

A great deal of effort has been spent trying to understand the consequences of M&A activity, but there are few areas of consensus. Some maintain that the M&A peak in the 1980s was mostly positive, correcting excesses of the 1960s wave of M&A, when large firms tried to diversify their business and stabilize their overall cash flows by buying smaller companies. Longitudinal studies of many transactions show evidence of increased productivity and profitability in acquired companies. Detractors point out that the 1980s M&A wave resulted in much increased corporate debt levels, which in turn forced companies to curtail current or planned spending on R&D, capital equipment, marketing, or other items considered discretionary in the short run. While some reductions in capital equipment purchase and R&D may be taken without severe damage for a time, prolonged reductions will cost a firm its ability to compete technically.

According to the evidence, M&A overall has had little or no direct effect on things like R&D spending. However, National Science Foundation (NSF) data show that high debt—which is characteristic of the 1980s-style takeovers, but not of friendly mergers and acquisitions—was strongly associated with a drop in R&D funding, while companies that did not undergo high-debt restructuring increased R&D funding. If the focus is narrowed from all M&A to hostile takeovers and defenses against them, the argument that takeovers are having deleterious effects on technology development, capital equipment spending, and general willingness to make long-term investments becomes stronger.

Institutional investors-mostly pension funds—account for the lion's share of the new short-term pressure. Pension funds and other institutional investors hold about a third of all outstanding stock, but are believed to account for more than half of all trading.[24] Pension and institutional fund managers, in turn, keep or lose their jobs depending on whether their stock portfolios have done as well as the market. Firms, responding to these powerful investors, feel pushed to maximize their own short-term profits, believing that the market will penalize them for long-term investments that dilute those profits.[25] The penalty is the threat of a hostile takeover. While only a few companies have actually experienced a takeover attempt, the possibility of facing one is viewed with great consternation by many businessmen, and many CEOs devote valuable time and resources to the problem. The irony is that some companies have acted to avoid hostile takeovers by plunging into debt to buy out shareholders, which can have an effect on the company's long-term performance similar to that of a hostile takeover itself, or the attempt to fight one off.

In some cases, hostile takeovers have had beneficial effects, replacing ineffective management and restoring control to managers whose companies were swallowed by large conglomerates unfamiliar with the business of their subsidiaries and uninterested in measures of performance other than profit. Few people, even the harshest critics of the wave of hostile, bustup takeovers of the 1980s, would advocate a cessation of all merger and acquisition activity; most agree that some threat of a hostile takeover is an important disciplinary force. Yet the relative ease of hostile takeovers in the 1980s—brought about principally by the availability of high-risk bonds for financing, and also by less stringent antitrust enforcement—has made the financial environment even less conducive to long-term investment than in the past.

Mitigating the pressure for short-term profits is not simple. Any policy change would have to be carefully crafted to have a substantial effect on market behavior yet avoid working too well and blunting the ability of shareholders to oust bad management.

Most of the proposals for changing investors' short-term time horizons are tax proposals. One that is often advanced is that Congress provide incentives for holding stocks for a longer period by reducing the rate of capital gains tax on gains from those stocks. Currently, capital gains are taxed like income, with a top rate that is, in effect, 33 percent.

[24]Alan Murray, "Capital-Gains Tax Bill Would Spur Asset Sales More than Investment," *The Wall Street Journal,"* Sept. 28, 1989.

[25]Michael L. Dertouzos, Richard K. Lester, and Robert M. Solow, *Made In America: Regaining the Productive Edge* (Cambridge, MA: The MIT Press, 1989), p. 62.

In the 1989 debates over lowering the capital gains tax rate, one of the options before Congress was to give preferential tax treatment-an effective rate of 20 percent over the next 2 years-for assets held for a year or more, rising to a top rate of 28 percent rate thereafter, but with the gain indexed to net out the effect of inflation. Another included a two-step schedule of capital gains tax: assets held for a year or more would qualify for indexing, and those held for 5 or more years would qualify for alternative preferential treatment, with the option of calculating taxable gains on 25 percent of the sale price rather than the full indexed value.[26] Another proposal, the Packwood-Roth bill, would allow individuals to exclude from capital gains tax a percentage of the gain, depending on how long the asset is held. Investors who have capital gains on assets held for less than 1 year could exclude 5 percent of the gain from tax; the amount excludable increases by 5 percent for assets held each additional year up to a maximum excludable gain of 35 percent, after 7 years. Earlier, the President proposed atop rate of 15 percent on all capital gains.

Some proposals would make more fundamental changes in the tax treatment of capital gains than any so far considered in the 101st Congress. For example, one scheme is to have a seven-step schedule of capital gains taxes, taxing very heavily (at 50 percent) those held for a year or less, and lightly (at 10 percent) those held for 6 years or more.[27] Another proposal would tax capital gains on securities held less than a year at 50 percent, and reduce the rate to 15 percent on gains on securities held for more than 5 years.[28] Both proposals also broaden the base for taxing all capital gains, to include institutional investors as well.

The above proposals, or a similar steeply variable schedule of capital gains tax to reward long-term investment, could help to lessen the pressures on managers to show short-term profits. It would also bean incentive for investors of all types to evaluate and monitor more carefully the performance and prospects of companies they invest in. That is all to the good; inattentive investors with short time horizons contribute little if anything to the management of business, and much less to technology development in the private sector. However, there are some potential problems as well. For example, investors might be unduly influenced by tax considerations to leave their money in companies with mediocre performance, blunting the signals the market is expected to give to managers. But the damage done by the short-term outlook to American manufacturing is severe enough to warrant serious consideration of significant changes in capital gains rates.

Although a variable capital gains tax schedule would encourage investors to hold assets longer, it would not by itself affect the group of investors most often cited as engaging in speculative turnover. Institutional investors-pension funds and investment funds for nonprofit institutions like universities—pay no capital gains tax. In order to quell the speculative turnover on the stock market, therefore, Congress might consider additional measures to change the incentives of either institutional fund managers or investment bankers who handle transactions. One proposal is to charge an excise fee on the pension funds' gains on stock turnovers if the stock is held for 180 days or less. Another is to subject these institutional investors to capital gains taxes.

Another possibility is to charge a transactions tax on all stock trading, or a securities transfer excise tax.[29] This would raise the costs of stock transactions, but would disproportionately discourage rapid, speculative turnover; the greater the turnover of stock, the greater the disincentive caused by the transactions tax. The securities transactions tax would also raise the cost of capital, but according to one analysis, not enough to match the beneficial effects of increasing corporate time horizons and reducing "the diversion of resources into the economy's financial sector. "[30] An added benefit of a securities tax is the revenue it raises; Summers and Summers estimate that a 0.5 percent tax would raise about $10 billion annually. Japan's securities transaction tax raised $12 billion last year. All of these

[26]Elizabeth Wehr, "Economists Fault Rival Plans for Capital Gains Cut," *Congressional Quarterly*, Aug. 19, 1989.

[27]Donald P. Babson, *United and Babson Investment Report*, vol. LXXXI, No. 1., Jan. 3, 1989

[28]Felix G. Rohatyn, "Instituional 'Investor' or 'Speculator''?" *The Wall Street Journal*, June 24, 1988.

[29]Lawrence H. Summers and Victoria P. Summers, "When Financial Markets Work Too Well: A Cautious Case for a Securities Transactions Tax," paper presented at the Annenberg Conference on Technology and Financial Markets, Washington, DC, Feb. 28, 1989.

[30]Ibid., p. 1.

proposals favor long-term investments, and could discourage those leveraged buyouts (LBOs), hostile takeovers, and junk bond transactions aimed at short-term speculation.

So far, none of these proposals has been subjected to thorough examination and public debate. Most of the legislative proposals made so far would confer a benefit to those who hold stock for more than a certain time (6 months or 1 year, in different proposals made before Congress), hardly long term by the standards our strongest international competitors have set. None of the legislative proposals considered so far would penalize those holding a stock for less than 6 months to 1 year, beyond taxing the gain at the marginal rates for ordinary income and retaining limitations on the deductibility of a loss. The potential risk-possibly reducing the liquidity of investments in securities, and thereby reducing the ability of the market to give appropriate signals to company managers—is real, but we do not yet know how great a risk this is. The issue centers on just how important taxes are, relative to other considerations, in the investment decisions of all kinds of investors. That is one of the most important questions to address in order to craft policies that continue to encourage investors to make their savings available to companies, but favor companies that are managed for long-term gain as well as short-term profit.

In addition to tax measures, a menu of other measures could be considered to return hostile takeovers to the role they played in the past—namely, a disciplinary force on poor management. They include extending the minimum duration of tender offers, outlawing greenmail and golden parachutes, shortening disclosure time when an investor has acquired more than 5 percent of a company's stock, and requiring tender offers in excess of 110 percent of share value to be made to all stockholders.[31] These are aimed specifically at hostile takeovers. But by most accounts such raiding is on the wane. If the flurry of junk-bond financing and hostile tender offers is subsiding, Congress has an opportunity to assess the effects of the bubble of restructuring activity, without the sense of urgency that caused many of the anti-takeover proposals to be raised. Some limits on the ability to make and finance hostile tender offers may therefore be worth considering, even though such limits will have to be balanced against the healthy and indeed necessary effects of takeovers on managerial performance. In an important sense, takeovers are the fundamental enforcer of market forces on individual fins; the trick is to keep the pressure on while ensuring that it doesn't get out of hand.

Environmental Uncertainty

American managers have long had to contend with a macroeconomic and political environment that was managed less for their welfare than for other purposes. Foreign policy, macroeconomic policy, international finance, and trade policy have at many times been conducted with scant consideration for the effects of different choices on the competitive position of American producers. When America was the world's dominant maker of most goods and had the best technology and manufacturing practice in a wide variety of industries, this was not a debilitating handicap. Now we must take it more seriously.

Although the process of making macroeconomic, foreign, and trade policy is not manifestly more indifferent to business (or manufacturing) competitiveness than it once was, the consequences of those policies are now more important. In many areas of obvious importance to the economy (e.g., parts of the semiconductor industry), American manufacturing is struggling to survive. Changes in the general economic and political environment that would have been inconvenient in the past could be crippling now.

This is not meant to suggest that the conduct of all our most important domestic and international policies be guided solely by the wish lists of American manufacturers. But we might consider building institutions that could advise policymakers in key areas on the effects of their choices on American competitiveness. Foreign policymaking, for example, is often at odds with the commercial interests of U.S. manufacturers. The Department of State has just one office that concerns itself with a commodity, rather than a country or region. That is the Textile Division of the Bureau of Economic and Business Affairs, the purpose of which is to keep trade frictions in textiles and apparel from interfering with the foreign policy aims of the Department. The U.S. Trade Representative's office and the Department of Commerce sometimes champion the

[31] Rand V. Araskog, "How I Fought Off the Raiders," *FORTUNE*, Feb 27, 1989, p. 118.

competitiveness of American manufacturing, but this is more a matter of the political persuasion of the appointees and administration currently in office than a standard practice.

There are many approaches to solving this problem, and various forms have appeared in legislative proposals over the past several years. One approach, often proposed, is to create anew, powerful voice in the cabinet for competitiveness interests—a Department of Trade and Industry, loosely patterned after Japan's Ministry of International Trade and Industry. Another and more difficult approach would be to create institutions within existing departments to represent competitiveness and manufacturing interests, and to build sensitivity to those concerns into all departmental decisionmaking. This, in fact, may be more like the Japanese approach than creating our own version of MITI. Nearly every Japanese ministry has strong incentives to consider the competitiveness of Japanese companies under its jurisdiction in creating and implementing policies. If Congress wishes to consider this approach, a thorough study of what those incentives are in Japan and other developed nations would be a good starting point.

HUMAN RESOURCES

Manufacturing managers, having grumbled for years about the shortcomings of American public schools and a poorly educated work force, have begun to speak of a crisis. Semi-literate machine fixers who used to repair machinery by looking at how it worked are baffled by computerized equipment stuffed with invisible electronic components; these machines need repairers who can read manuals and diagrams. Young people leaving school with meager math skills are not prepared to deal with computer printouts and digital analyzers to monitor quality on the assembly line.

Some large companies are trying to deal with the problem by educating employees themselves. Motorola, for example, estimates that from 1989 to 1993 it will have spent $35 million teaching its workers reading and arithmetic. Motorola is committed to educating workers already on its payroll, but has become more selective in hiring; it no longer takes people who cannot do fifth-grade math and seventh-grade reading. At that, said a company vice-president, '' We've had situations where we couldn't open the factory because we didn't have the work force."[32]

The situation threatens to get worse before it gets better. More than half the net growth of the work force from 1986 to 2000 will be from minority groups,[33] and a great many minority children (38 to 45 percent) are growing up poor. Poor children drop out of school in disproportionate numbers, and many emerge sadly lacking in the skills they need for economic survival. David Kearns, chairman of the Xerox Corp., sees in this the 'makings of a national disaster."[34]

Few issues on the domestic front have received as much attention in the past few years as the sorry results of American public schooling. Indeed, it is hard to overstate the importance of better education in the basics, not only for national competitiveness but also for a peaceful and prosperous society--one which gives most people a chance at decent jobs and a middle class livelihood. However, this report concentrates on the factory rather than the school room, and thus does not attempt to add much to the many recent analyses and proposals for improvement in our children's basic education. Other OTA assessments, examining various aspects of education and training, have analyzed some public policy issues that are particularly relevant to manufacturing performance.[35] The discussion below flags some of these issues and describes them briefly, without analyzing specific policy options.

32Cindy Skrzycki, "The Company as Educator: Firms Teach Workers to Read, Write," *The Washington Post,* Sept. 22, 1989, p. G1.

33According to the Bureau of Labor Statistics, 57 percent of the 20.9 million net growth in the labor force from 1986 to 2000 will come from minority groups (6 million Hispanic, 3.6 million Black, and 2.4 million Asian and other). Ronald E. Kutscher, "Overview and Implications of the Projections to 2000," *Monthly Labor Review,* September 1987, pp. 3-4.

34Edward B. Fiske, "Impending U.S. Jobs 'Disaster': Work Force Unqualified to Work," *The New York Times,* Sept. 25, 1989, p. 1.

35U.S. Congress, Office of Technology Assessment, *Educating Scientists and Engineers: Grade School to Grad School,* OTA-SET-377 (Washington, DC: U.S. Government Printing Office, June 1988); *Technology and Structural Unemployment: Reenjoying Displaced Adults,* OTA-ITE-250 (Springfield, VA: National Technical Information Service, 1986); *[international Competition in Services,* OTA-ITE-328 (Springfield, VA: National Technical Information Service, 1987), chs. 7, 8, and 10; and the forthcoming assessment "Worker Training: Implications for U.S. Competitiveness" (publication expected fall 1990). OTA has also conducted a several assessments of technology and public school education; two recent ones are *Power On! New Tools for Teaching and Learning, OTA-SET-379* (Washington, DC: U.S. Government Printing Office, 1988) and *Linking for Learning: A New Course for* Education, OTA-SET-430 (Washington, DC: U.S. Government Printing Office, November 1989).

Training the Active Work Force

Essential though it is, improvement of public schooling is a longrun proposition. Children entering the first grade in 1990 will leave high school in 2002, and effective education often begins sooner (as in the Headstart program, which starts at age 3) and ends later. Thus, even if we improved public education radically, starting tomorrow, the full results would not show up in the work force until well into the 21st century.

A more immediate approach to improving human resources for manufacturing is to help people already in the work force gain the skills they need for modern jobs. ''Skills training" covers abroad range, from upgrading basic math and reading abilities to mastery of a complex craft. Often the most urgently needed skills are the basics, so that workers can understand operating manuals and take part in statistical process control for quality. In addition, worker training is only one aspect of improving human resources for manufacturing. Managers also need training in organizing work and using people effectively in relation to new technologies. Giving shopfloor workers a genuine stake in the company and real responsibilities for better quality and greater efficiency; promoting team work (among engineers as well as operatives); organizing work to make the most of people's abilities-all these things add up to skillful management of human resources.

The Federal Government has had a long but generally not very close or direct involvement in training of adult workers who want to upgrade their skills. The most pervasive Federal influences are indirect: in government-guaranteed student loans, which workers can use for taking part-time courses while they hold down jobs; and in the tax laws that let employers deduct the costs of employee training from taxable income and, in some cases, allow workers to deduct what *they* pay.[36] The biggest direct Federal involvement is in the armed forces, where training and R&D in how to provide it have been major concerns since World War II. Some computer-based training technologies developed for the armed forces have found their way into workplace training on the civilian side.[37] Aside from the military sphere, Federal activity is minor. A small program that partially funds demonstration projects for teaching literacy at workplace sites is greatly oversubscribed. Congress provided $9.5 million for it in 1988, and a flood of proposals came in, requesting a total of nearly $100 million; the program was funded at $11.9 million in fiscal years 1989 and 1990. Another small effort on the Federal Government's part is encouragement and technical assistance for employee involvement projects, provided by the Federal Mediation and Conciliation Service and the Labor Department's Bureau of Labor-Management Relations and Cooperative Services.

Some of the States are far more active than the Federal Government in supporting workplace training. Illinois, for example, in its Prairie State program pays half the direct cost of worker training courses for companies that are in trouble (as shown by their tax returns). Typically, the companies are small ones and the training is very often in statistical process control-something that larger companies are increasingly demanding of their suppliers. Several States that run industrial extension programs, offering technical assistance to small manufacturers, have found that training is an absolutely essential ingredient in the adoption of new technologies.[38] At least one program, the Michigan Modernization Service, systematically pairs training with technology extension. In supporting State technology extension programs or developing Federal centers that provide such services (see the discussion below), the Federal Government might insist that training be provided along with advice and assistance in acquiring advanced equipment.

A full examination of policy issues surrounding the retraining of active workers will appear in a forthcoming OTA report, *Worker Training: Implications for U.S. Competitiveness.*

[36] Deductions for individuals are limited to work-related mining, and can be taken only if the amount spent for training plus all other miscellaneous deductions is more than *2* percent of the taxpayer's adjusted gross income, Material hereon the Federal role in workplace training is abstracted from work in progress on OTA's forthcoming assessment of "Worker Training: Implications for U.S. Competitiveness. "

[37] Spending by the Department of Defense on R&D for educational technologies is eight times the combined spending of the National Science Foundation and the Department of Education ($56 million a year, on average, v. $7 million). CharleBlaschke et al., "Support for Educational Technology R&D: The Federal Role," contractor report prepared for OTA Sept. 30, 1987, p. vi., for the assessment *Power On!* (op. cit.)

[38] See the discussion of this point in the section entitled "Industrial Extension" in ch. 7.

Supply of Engineers: Keeping the Pipeline Filled

In the next decade or so, it could become much harder than it is today to maintain an adequate supply of technically competent people for manufacturing, especially engineers. In the mid to late 1980s, most analysts found that there was little evidence of a real shortage of engineers in the United States—yet.[39] Also, the United States was about on a par with Japan, Germany, and other advanced countries in the proportion of engineers in the work force (see ch. 4). But it looks as though this parity will not last long; Japan is now graduating far more engineers per capita than the United States.

Demographic facts suggests that maintaining even the present level of supply could become more difficult over the next 10 or 15 years. A growing proportion of the young people coming through the educational pipeline are from minority groups, and up to now minorities have been very much underrepresented among engineers. Blacks are 12 percent of the population and Hispanics 9 percent; each were below 2 percent of all employed engineers in 1986. Women, too, are underrepresented in engineering; they are 45 percent of the Nation's work force, but only 4.1 percent of employed engineers. That rate rose from 1.6 percent in 1976, however, and will continue to rise, since nearly 15 percent of engineers graduating with a bachelor's degree in 1986 were women. The proportion of blacks among employed engineers rose more slowly over the 10 years, from 1.2 to 1.7 percent.[40]

Public policy has not been heedless of the fact that white males-predominant in science and engineering in the past-are a dwindling proportion of new entrants to the labor force. Several Federal agencies offer special scholarships and grants to encourage minority students, or women, or both, to study science and engineering in college or graduate school;[41] some also offer programs such as summer internships to stimulate interest in science and math among minority high school students.[42] Many of these programs have scored good results, and deserve support. But they are inevitably limited. The inclination toward a choice of science or engineering usually comes early. Children who decide in elementary school that they don't like or can't learn math are not likely to see themselves as engineers when they grow up. This means that, to really open wider opportunities to all children to choose engineering careers, we must do a better job of teaching math and science from the beginning.

Meanwhile, retraining of midcareer engineers, like the retraining of adult workers in general, could help to shore up the supply of engineers available to manufacturing in the next few years. If funding for the Department of Defense declines as expected with the melting of the Cold War, some of the engineers doing military work will likely lose their jobs. Part of a U.S. Government program for easing the transition from military to civilian production and employment could be providing retraining opportunities specifically designed for engineers With government support, retraining courses might be developed to fit the needs of manufacturing—something that is generally neglected in university engineering departments.

Manufacturing Education and Research

The quality of engineering is as important to manufacturing performance as the quantity. The elitism of design engineers and their remoteness from problems of manufacturing ("throwing the design over the wall") are well-known failings in American manufacturing. Insofar as these are problems of management, there is little that government can do about them directly. However, efforts to encourage more interaction between the design center and the shop-floor (such things as designing for manufacturability and simultaneous product and process engineering) also involve education and

[39] U.S. Congress, Office of Technology Assessment, *Demographic Trends and the Scientific and Engineering Work Force--A Technical Memorandum, OTA-TM-SET-35* (Springfield, VA: National Technical Information Service, 1985), pp. 92-109; *Higher Education for Science and Engineering—A Background Paper, OTA-BP-SET-52* (Washington, DC: U.S. Government Printing Office, 1989), p. 14 ff.

[40] National Science Foundation, *Profiles—Electrical/Electronics Engineering: Human Resources and Funding*, NSF 88-326 (Washington, DC: U.S. Government Printing Office, 1988).

[41] The MARC program (Minority Access to Research Careers) of the National Institutes of Health is a good example of such programs. It has done well at bringing minority students into science careers, and currently provides 410 undergraduate scholarships and 69 graduate and faculty fellowships. For a brief description, see OTA, *Educating Scientists and Engineers, op.* cit., p. 54.

[42] Federal agencies also provide math and science internships for high school students, college scholarships, and teacher training sessions and model courses that are open to everyone.

research. For example, simultaneous engineering is a difficult technical as well as management challenge. The technical problems might eventually be solved with more R&D attention and more powerful computers. In education and research, the government does have some leverage.

Few American universities have departments of manufacturing engineering, nor do they offer much education and research relevant to manufacturing in their other engineering departments. This is partly a matter of money. Manufacturing R&D gets little Federal funding; it probably received well under 1 percent of the total $65 billion the U.S. Government spent for R&D in 1989, and nearly all of that came from the Department of Defense.[43] Other Federal support for manufacturing R&D is truly meager. The Center for Manufacturing Engineering of the National Institute of Standards & Technology was funded at $6.2 million in fiscal year 1989. Technology awards by the National Science Foundation's Manufacturing Systems Division were about $6.5 million, out of NSF's total of $1.5 billion grants and awards. The NSF-sponsored Engineering Research Centers at 18 universities received about $33 million; some (not all) of these centers emphasize manufacturing R&D, and are giving engineering students cross-disciplinary training that is valuable to manufacturing companies (see the discussion of ERCs below). One option for raising attention to manufacturing in universities beyond the present level would be to elevate the NSF's Manufacturing Systems Division to a Manufacturing Sciences Directorate. This would provide a solid, prestigious base for government support of research and education specifically focused on manufacturing.

DIFFUSING MANUFACTURING TECHNOLOGY

Throughout the 1980s, Congress has taken a number of actions to transfer advanced technologies from labs to factories, bring smaller firms up to date in manufacturing technology, and modify laws that may interfere with technology advancement in manufacturing. Some of these actions are well along; others have barely begun. Not one of them, by itself, is likely to have any very dramatic effect, certainly not overnight, Some, after a fair try, will pan out and others will not. Given patience and an open-minded experimental approach, it is likely that some combination of these measures could make an appreciable difference in improving manufacturing performance.

Some of the most promising options are similar to Japanese government programs (national and local) that have served that country's manufacturing firms for years. There are of course many economic, social, and political differences between the United States and Japan; not everything that works there would work here. However, as discussed below, several of these Japanese programs do seem to be quite adaptable to American conditions.

Technology Extension

One way for government to help manufacturers adopt improved technologies is through various kinds of technology extension services. A few States are providing services of this kind with a good deal of success. This is one of the programs that works well in Japan. The nationwide network of technology extension services in Japan is much used by small and medium-size manufacturers. (See chs. 6 and 7 for discussions of the importance of smaller manufacturers to U.S. competitiveness and descriptions of government programs in Japan and the United States that offer small firms technology assistance.)

Until very recently, Federal involvement in technology extension was minimal. The States have done more, but even so, in 1988 the combined technology transfer and technology/management assistance programs of 30 States added up to only $58 million-and this figure overstates technology extension to manufacturers, since it includes management assistance of various kinds to all sorts of businesses (see ch. 7 for details). The total for State technology extension services was probably between $25 million and $40 million.

In 1988 Congress created a framework for a broader Federal program of technology extension. The Omnibus Trade and Competitiveness Act of 1988 authorized several kinds of technology assistance to manufacturers, including Manufacturing Technology Centers to demonstrate advanced tech-

[43] Federal spending on R&D related to manufacturing was no more than about $400 million in fiscal year 1989, and may have been less; precise figures are not available. U.S. Congress, Office of Technology Assessment, "U.S. Manufacturing: Problems and Opportunities in Defense and Commercial Industries," staff paper, December 1989.

nology and provide extension services, especially to smaller firms; Federal assistance to State technology extension programs; and the Advanced Technology Program, a mechanism for Federal guidance and participation in joint R&D ventures with private business. The actual performance of these programs has been modest so far. In fiscal year 1990, Congress appropriated $7.5 million for the Manufacturing Technology Centers and, for the first time, funded aid to State programs, at $1.3 million.[44] A smattering of older Federal programs also provide some technology extension services.

At current levels, the combined Federal and State technology extension programs cannot reach more than a small fraction of the country's 355,000 small and medium-size manufacturing firms-those that are most likely to need technical assistance. As noted in chapter 7, one of the most valuable kinds of technology extension is customized advice to individual manufacturers. Giving that service to just 7 percent of smaller manufacturers would cost a total of $120 million to $480 million a year, depending on the level and quality of service.

If Congress wishes to deepen its commitment to technology extension, several choices are open. It could provide more funds for Manufacturing Technology Centers under the Federal aegis. It could set up a more generous program of Federal matching funds to State industrial extension services than the present law authorizes. Or it could do some of both. These choices are discussed below.

The Federal Program: Manufacturing Technology Centers

The Omnibus Trade and Competitiveness Act of 1988 gave the National Bureau of Standards new responsibilities for technology transfer to manufacturers and renamed it the National Institute for Standards and Technology (NIST). One part of the law directed NIST to help create and support non-profit regional centers for the transfer of manufacturing technology, especially to small and medium-size firms. The tasks of the Manufacturing Technology Centers (MTCs) are to transfer technologies developed at NIST to manufacturing companies; make new manufacturing technologies usable to smaller firms; actively provide technical and management information to these fins; demonstrate advanced production technologies; and make short-term loans of advanced manufacturing equipment to firms with fewer than 100 employees.

The trade act authorized $20 million a year for NIST technology extension, but appropriations have been much less—$5 million in fiscal year 1988, $6.85 million in 1989, and $7.5 million in 1990. NIST has signed 6-year agreements with three regional MTCs, giving each $1.5 million per year for 2 years in succession, through calendar year 1990. (The remainder is for administrative expenses and other technology extension activities.) The Centers must match at least half the Federal dollars for the first 3 years and an increasing share thereafter; under the law, the Federal share declines to zero at the end of 6 years.

Japan's nationwide network of public testing and research centers, which provide technology extension services to smaller manufacturers, has many features in common with the NIST centers but is far more extensive. In 1985, there were 185 of these testing and research centers; they had 7,000 employees and annual funding of 66 billion yen ($470 million at 140 yen to the dollar), half from the national government and half from the prefectures. In addition, many Japanese cities, wards, and other localities have industrial halls that offer much the same kind of services. (See ch. 6 for details.)

In running the new manufacturing technology program, NIST officials say they are not just passing along Federal money but are taking an active hand in advising the Centers and learning along with them. Centers are encouraged to work with State programs and take advantage of State resources and experience. One of the criteria for selecting operators of the Centers is that they have previous links with State and local extension programs. NIST has also set up monthly meetings of all the Centers so they can learn from each other.

A key question about the future of the NIST technology extension program is how it can best be meshed with State extension programs that aim to do much the same thing, with as much coverage and as little overlap and re-invention of the wheel as possible. The 1988 trade act made some provision for Federal support of State technology extension programs, but in quite limited ways, as the next section describes.

[44] The Advanced Technology Program, discussed in a later section of this chapter, also got its first funding, $10 million in fiscal year 1990.

Federal Assistance to State Programs

The 1988 Omnibus Trade and Competitiveness Act also set up a limited program of Federal assistance to State technology extension programs. Included was a nationwide study of State technology extension services; technical advice on how to transfer Federal manufacturing technology to firms; and a clearinghouse for information about State technology programs. The act also authorized a small program of Federal financial aid to State technology extension programs that already exist and want to expand. States would have to increase their own funding by the same amount as the Federal contribution. Their proposals would be judged by how many new firms they proposed to help under the cooperative Federal-State agreement, whether they could maintain service after the agreement expired, and to what extent they intended to demonstrate new and expanded uses of Federal technology.

As this report was written, NIST's State technology extension program had just begun, having received its first finding of $1.3 million in fiscal year 1990. On reprogrammed funds, NIST had already done the study of State technology extension services[45] and started a small, one-man effort to acquaint State agencies with NIST services and resources. The clearinghouse was just getting organized, and Federal financial aid to State programs was in the planning stages.

In its study of State programs, NIST defined "technology extension services' as programs whose primary purpose is to provide direct consultation to manufacturers for technology deployment. It found only 13 State-supported organizations in 9 States that fit the definition. More and more States, however, are taking an interest in technology extension, and at least one new program (Nebraska's) was created shortly after the survey was done.

Although the State programs are few, scattered, and mostly quite new, they are, on the whole, better developed than technology extension services at the Federal level. One or two have years of experience behind them and have built up outstanding reputations. For example, Georgia Tech's statewide industrial extension service dates back over a quarter of a century and is so much in demand that it refrains from any advertisement (see ch. 7). The Michigan Modernization Service is less than 5 years old, but it has gained a solid reputation and demands for its services are growing; its budget rose 40 percent in 1989.

Getting the Job Done: Federal or State Programs, or Both?

Despite the present flurry of State and Federal interest in technology extension to manufacturers, the actual coverage of such services is still very small. It doesn't begin to compare with the Agricultural Extension Service, with its funding of more than $1.2 billion (31 percent Federal), its offices in nearly every county in the 50 States, its 9,650 county agents, and its 4,650 specialist scientific and technical staff.[46] To put this in perspective, consider that agriculture contributes 2 percent to the gross national product, and manufacturing 19 percent.

Before taking up the question of who can best provide technology extension services, it is worth stepping back and considering what a comprehensive nationwide system might look like. Since manufacturing industries are regionally concentrated, technology extension centers would not be evenly distributed across the country. In areas of sufficient concentration, some centers could focus on technologies for just one industry or group of industries (e.g., electronics suppliers, auto parts and components makers), while others would be more eclectic.

If the average center served about 200 clients per year, and if 24,000, or just 7 percent, of the Nation's 355,000 small and medium-size manufacturing firms took advantage of the services, then about 120 centers might be needed. This is a modest number, based on the experience of the Georgia Tech

[45] The National Governors' Association conducted the study under contract for NIST. Results were published in Marianne K. Clarke and Eric N. Dobson, *Promoting Technological Excellence: The Role of State and Federal Extension Activities* (Washington, DC: National Governors' Association, 1989.)

[46] Two studies have found high rates of return on investments in agricultural research, extension, and farmers' schooling. One study estimated internal rates of return (value of agricultural product/research and extension expenditures) of 27 percent on such public investments in the State of Virginia (George W. Norton, Joseph D. Coffey, and E. Berrier Frye, ''Estimating Returns to Agricultural Research, Extension, and Teaching at the State Level,'' *Southern Journal of Agricultural Economics*, July 1984). The other study found a social internal rate of return to public crop research of 62 percent, and 15 percent to farmers' schooling (Wallace E. Huffman and Robert E. Evenson, ''Supply and Demand Functions for Multiproduct U.S. Cash Grain Farms: Biases Caused by Research and Other Policies,' *American Journal of Agricultural Economics,* August 1989.)

industrial extension service. The Georgia Tech service, with 13 small offices statewide and a staff of 26 professionals, makes site visits to about 480 clients per year, usually limits service to 5 days, and, as noted, does not advertise, for fear of attracting more clients than it can serve.[47] Georgia has about 2 percent of the manufacturing establishments in the United States. If other areas provided industrial extension at only the same limited level, and each center served about 200 clients per year, the centers would number 120, the staff 3,120, and the clients about 24,000.[48]

These figures are based on the assumption that the technology extension services do a good job and prove to be worth what they cost. Assuming that they do, a nationwide technology extension service obviously cannot arise overnight. There is room for expansion of both State and Federal centers, and it will take time. The question is whether one or the other is better suited to provide the services. It is often thought that States, being in closer touch with their own citizens, do a better job of providing business and technical services. On the other hand, regional concentrations of industries cross State lines, and it is usually difficult for States to combine forces and provide services on a regional basis. Still more important, some States simply do a better job than others, and the interest in improving manufacturing competitiveness is more than parochial; it is national.[49]

A combination of State and Federal programs might best serve the national interest. (It is worth noting that Japan's technology extension network combines national, regional and local support, with the national government and prefectures sharing equally the funding 185 centers nationwide, and local governments funding more centers on their own.) Federal grants to support expansion of experienced, high quality State programs and technical assistance to bring newer ones along could be an efficient use of resources. At the same time, there are benefits in having Federal programs as well. Federal officials who supervise technology extension have the advantage of frost-hand knowledge, which is valuable in evaluating State programs. Federal technology extension centers may be especially useful in places where concentrations of one industry or allied industries cross State lines, or in areas that are otherwise underserved.

If Congress decides to support the expansion of State programs, it might consider raising the present authorization of ***$2*** million in Federal matching grants. That sum would not go far toward building a comprehensive nationwide network of technology extension services. Suppose that within 5 years the U.S. Government is contributing to the support of 60 State programs, each with total funding of $1 million to $4 million a year, depending on the level of service. If the Federal share were 30 percent (as it is in the Agricultural Extension Service), that would amount to $18 million to $72 million a year. These are extremely modest assumptions. If a nationwide program were even as large, in proportion, as the Georgia Tech extension service, it would include 120 centers and cost the Federal Government $36 million to $144 million a year.

Congress might also consider removing the condition that State programs, to receive funding, must demonstrate methods to increase uses of Federal technology. Helping U.S. manufacturers make better use of technology, whatever the origin of the technology, is in the national interest.

As for Federal Manufacturing Technology Centers, Congress may wish to reconsider the law's sunset provision, under which Federal funding stops after 6 years. NIST officials expect that the Centers will generate some income themselves by charging some fees for service, but that they will rely mainly on State funds as Federal funds are phased out. If Congress considers technology extension a matter of continuing interest, it may want to extend Federal funding at some level beyond the 6 years. Stability and predictability is an important ingredient in the success of institutions like these, and continued Federal funding is a factor in stability.

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[47] The Georgia Tech program seines the same number of clients without site visits—a total Of about 960 per year.

[48] The estimate of the size of a minimal nationwide extension service is based on the lower number, i.e., the 480 clients receiving site visits.

[49] Some Federal programs that offer grants t. States, with very little in the way of oversight or guidance, have run into the problem of uneven level and quantity of service in different States. An example is the displaced worker reemployment and retraining program of the Job Training Partnership Act, See U.S. Congress, Office of Technology Assessment, *Technology and Structural Unemployment: Reemploying Displaced Adults*, OTA-ITE-250 (Springfield, VA: National Technical Information Service, 1986).

Financial Aid for Modernizing Manufacturing

Technical assistance is one part of the prescription for improving the technology base in American manufacturing, especially for small and medium-size enterprises that do not have a large or diverse technical staff. Another part is money. Unless a small firm has an outstanding track record, it will generally have a harder time raising money for purchase of new production equipment than will a large one. It is hard enough for large U.S. firms to match the capital investment rates and R&D spending of their best foreign competitors, in view of the high interest rates in the United States and a financial climate that rewards short-term profits more than Iong-term improvement in market share (see ch. 3). For smaller fins, the difficulties are often compounded.

There are many U.S. laws on the books that give special breaks to small business.[50] For example, the Buy American laws governing purchases by U.S. Government agencies give American firms a 6 percent price advantage (the agency must buy American unless the price of the foreign-made good is at least 6 percent lower); but for small businesses, the price advantage is 12 percent. Another example is the Small Business Innovation Research program, which sets aside about $350 million of Federal R&D money per year for small businesses (see ch. 7).

Also, there are special guaranteed loan and subsidized capital programs for small businesses. Direct Federal loans to small business are limited to special groups (disabled veterans, the handicapped, low-income people), and totaled only $47 million in fiscal year 1989. (Direct Federal loans to small business were virtually abolished in the Reagan years, on the philosophical grounds that government loans were an interference with efficient allocation of resources through the free market.) Federally guaranteed commercial loans to small business amounted to $3.6 billion.[51] In addition, the Federal Government subsidizes the Small Business Investment Corporation and the Minority Small Business Investment Corporation, which make equity investments as well as long-term loans to small fins. Congress appropriated $154 million for these two programs in fiscal year 1989, and the corporations made investments amounting to $715 million. All of these financial programs, it should be noted, are for all kinds of small and mid-size businesses, not just manufacturers.

The point of most of these programs is to give general support to smaller businesses on the grounds that they are dynamic and entrepreneurial, and contribute to economic growth and flexibility. The programs have rarely been designed for the specific purpose of promoting effective use of manufacturing technologies. This contrasts with the Japanese approach. In Japan, financial aid to small firms is not only very much larger-some $27 billion in direct loans from national government programs and an additional $56 billion in loan guarantees (again, to all kinds of small and mid-size businesses, including a great many in the service sector)--but also, much of the financial aid is tied to technical assistance and some is directly targeted to technology improvements (see ch. 6).

Some options for linking government financial aid to manufacture with technological improvements, and possibly raising the amount, are discussed below.

Equipment Leasing

To encourage the adoption of modern manufacturing equipment, Congress might consider creating a government-supported equipment leasing system that would: 1) make available to manufacturers (especially small companies) new production equipment on easy terms; and 2) provide an assured market for at least part of the output of companies making production machinery.

The Japanese government's equipment leasing system, under which small and mid-size companies can lease new equipment or buy it on the installment plan at less than market rates, is a key technology-promoting measure, and one that seems reasonably adaptable to the United States. The Japanese system was frost created in 1966, but a new part was added in 1986 that applies specifically to computers and ''mechatronics" —such things as numerically controlled (NC) machine tools and robots. Both the

[50] In the United States, the term ''small business" usually means firms with fewer than 500 employees, and thus includes medium-size business as well. In Japan, the term small and medium-size enterprise (SME) usually means firms with fewer than 300 employees.

[51] Federally guaranteed loans were kept at nominally the same level from fiscal years 1980 through 1989 (about $3.5 billion per year), although prices rose by 47 percent over the period, reducing the amount of real dollars.

national government and the prefectures contribute funds to the system; in 1987, leases and installment sales worth 49 billion yen ($350 million, at 140 yen to the dollar) were made under the system. Besides supporting this frankly subsidized system, the Japanese Government has also provided capital for quasi-public leasing corporations that serve larger as well as smaller companies. One of these is for lease of computers, another for robots (see ch. 6).

Small companies benefit from the leasing system in several ways. If they are strapped for cash, they don't need a downpayment; if they are not sure of the economic benefits of a new piece of equipment they can try it out without committing to it; and the system provides technical consultations and guidance on what equipment they need. Besides these benefits for users, the system also provides a substantial, stable market for manufacturers of production equipment (e.g., machine tools).

If Congress wishes to create and support such a system for the benefit of users only, the country of origin of the equipment does not matter. But if the system is designed to build up the capacity of U.S. makers of production equipment as well, then it would be necessary to define what a U.S. company is. The limited American experience with providing government help to private industry in improving manufacturing technology does not offer much guidance on this question. The answer might vary depending on practical circumstances. If one main purpose of a government-subsidized leasing program were to rebuild the U.S. toolmaking industry, it might make sense to restrict the purchases to machine tools made in this country, perhaps by U.S.-owned companies. (Such a requirement might be phased in, since it might be against the interests of machine tool users if U.S.-made machines were not as good as foreign-made machines.)

A government-supported leasing system could be set up in various ways. It might be open only to small firms or to all firms without regard to size. If open to all, it might give more favorable terms to small firms if it were open only to small fins, the government could also support in a less direct manner (i.e., provision of capital on favorable terms) a quasi-public leasing company that would be open to all.

Should Congress be interested in creating an equipment leasing system, an opportune place to start might be in the effort just getting underway to develop a next-generation controller for machine tools to be made in the United States. The National Center for Manufacturing Sciences (made up of about 90 manufacturing firms, large and small) and the U.S. Air Force are sponsoring a 3- to 5-year joint project to promote the development of a new, U.S.-made, single-standard computer controller for NC machine tools. A government-supported leasing system could provide some assurance of a market for U.S.-made machine tools using the new controller, and could add impetus to the R&D effort. If Congress wants to start small, on an experimental basis, with a government-supported leasing system, this could be a place to begin.

An equipment leasing system for NC machine tools could start with quite modest funds. Total sales of NC machine tools in the United States amounted to $1.7 billion in 1988; one-quarter of that ($425 million) was spent for U.S.-made machines. U.S. producers of machine tools (all kinds, not just NC) lost an average of 11 percent per year in sales from 1981 through 1988. Suppose they regained sales of NC machines at an average of 10 percent per year; in the first year, their sales would rise by $43 million. Suppose the government leasing system bought roughly 30 percent of the incremental output, or 13 million dollars worth, and leased it at a subsidized rate of about 80 percent of the sales price (i.e., a 20 percent subsidy). Then the cost of the program would be $2.6 million for that year, plus a modest sum for administrative expenses, less the taxes firms would pay on their increased profits.

A question that is always asked about schemes such as this is whether they really encourage wider diffusion of manufacturing technologies, or whether the government is simply subsidizing purchases that companies would make anyway. No certain answer can be given, but it seems likely that there would be some real encouragement. First, experience suggests that government purchases are a genuine factor in promoting the development and manufacture of new, advanced products; this incentive applies to the makers of the machinery. As for users of the machinery, a 1987 survey of representative metalworking companies found that uncertainty about demand for the companies' products and lack of financial resources were the biggest obstacles to investment in new plant and equipment. In plants without any NC machines (or other programmable automated equipment), managers gave as a leading

reason that the payback period was too long.[52] Leasing the equipment could help managers cope with the uncertainty about demand, and subsidies embedded in the leasing program would lessen concern about financial resources and payback periods.

Tying Technical Assistance to Financial Aid

In the United States, government financial aid to small businesses is not necessarily aimed at technological improvement. But it could be shaped to serve that purpose. For example, Congress might wish to require a technical assessment as a condition for a firm's getting a federally guaranteed loan or capital from one of the federally subsidized small business investment corporations.[53] But this requirement makes sense only if a government-supported extension service exists and is able to supply competent people to make the assessment. Any such requirement would probably have to wait for the development of a much more extensive network of technology extension services than the United States has today.

Another caveat is that government-supported loans and capital investments in small business are currently a minor source of business financing—about $3.8 billion in 1989. To put this in some perspective, all freed investment (in structures, plant and equipment) by all private business was $487 billion in 1988. Moreover, since only about 9 percent of small American enterprises are in manufacturing, it is unlikely that more than a small portion of the U.S. financial aid to small businesses goes to manufacturers. Furthermore, the aid probably reaches very few fins. In fiscal year 1988, 16,469 federally guaranteed loans were made to small businesses, and the quasi-public small business corporations made a total of 4,137 financing. If small manufacturers got a proportionate share of these guaranteed loans and subsidized financing, then 1,915 small manufacturing firms benefited—about one-half of one percent of the 355,000 small manufacturing firms in the country. Even if technical assessment were a condition forgetting financial help, not many small manufacturers would get either one.

This raises the question of whether U.S. Government financial aid to encourage the adoption of new technologies, especially by small fins, is too skimpy. Recognizing that there is no exact parallel between the two countries, it is still notable that Japanese loans and loan guarantees to small firms are at least 20 times as high as U.S. Federal financial aid to small business.[54] Moreover, the amount of subsidy in the Japanese loan programs is often greater. Some examples: In the United States, the terms for federally guaranteed loans are negotiated between the borrower and private lender, but interest rates can be as high as 2 3/4 percent above prime. In Japan, interest charges on such loans are generally well below the market rate. For instance, the Equipment Modernization Loan Program (which made direct loans of about $300 million in 1988) lends up to half the amount of the equipment purchase, and charges no interest.

In many ways, Japanese and American small manufacturing are not really comparable. Manufacturing in Japan is much more weighted to small fins, which account for 74 percent of Japanese manufacturing employment but only 35 percent in the United States.[55] Although total manufacturing employment is higher in the larger U.S. economy (19.4 million vs. 14.5 million in Japan) the number of employees in small and mid-size manufacturing firms is nonetheless greater in Japan (10.7 million v. 6.8 million in the United States).

Considering the political and economic differences between the two countries, Japanese policies obviously cannot be a template for U.S. policies. Yet the great disparity in assistance to small businesses does suggest that some higher level of aid to small

[52] Maryellen R. Kelley and Harvey Brooks, *The State of Computerized Automation in U.S. Manufacturing,* Harvard University, John F. Kennedy School of Government (Cambridge, MA: October 1988). Managers of plants with no programmable automation also gave technological reasons for non-adoption, the major one being that there were too few repeat runs to make the initial programming worthwhile.

[53] Management assistance is available from the Small Business Investment Corporation and the Minority Enterprise Small Business Investment Corporation, but is not a condition of getting capital funds from the corporations.

[54] Many States have special lea, grant, or capital investment programs for small businesses. OTA is not aware of tiny estimate for the total of financial aid to small business in all States, nor of any similar estimate of financial aid from prefectures, cities, or other local governments to Japanese small firms.

[55] In Japan, SMEs are defined as fires with fewer than 300 employees; in the United States, fewer than 500 employees. Also, SMEs contribute 56 percent of value added to manufacturing in Japan, 21 percent in the United States. Employment, rather than value added, is used here as an indicator of the importance of SMEs in manufacturing because the biggest component of value added is wages, and in both countries wages are substantially lower in small manufacturing firms than in large ones.

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U.S. manufacturing firms is worth considering as a way to raise their technological level and make them more competitive. Government help to small U.S. manufacturers could be especially significant, since it is uncommon in this country for large customer firms to give financial or technical aid to their suppliers. By contrast, many Japanese subcontractors get some financial support from their customer firms and a great deal of technical assistance.

If Congress wishes to consider an option of greater financial aid to small manufacturers, expansion of guaranteed loans, which takes advantage of the existing private banking system, probably has more appeal than resurrection of direct loans. The disaster of the 1980s with Federal savings and loan insurance might argue against any new or expanded program of Federal financial guarantees. However, other loan guarantee programs, such as the Federal Housing Administration's guarantees for home mortgage loans have a better record. With the backing of the government guarantee, banks can offer lower than market rates for FHA mortgages and lower requirements for downpayments and borrowers' incomes. At the same time, an FHA inspection provides some assurance that the property subject to the loan is sound. This program can be reckoned a success. At least until the great inflation in real estate of the 1970s, FHA-backed loans made it possible for people of quite modest means to own a home. Although the default rates on FHA loans have risen somewhat in recent years, they have generally been moderate. Default rates on the quite limited program of federally guaranteed loans to small business are also moderate.[56]

If Congress should decide to raise the amount of Federal loan guarantees for small manufacturers, options for tying financial aid to technological improvement assume greater importance. One option would be to target new financial aid to investments in advanced equipment. The Japanese Government has done this through its special leasing program for high-tech electronic and "mechatronic" equipment, open to smaller manufacturers, and also through selective tax breaks for high tech investments (described below). There is evidence that these targeted programs worked in Japan. After they were offered, there was a surge in purchases of NC equipment. (One Japanese manufacturer called it 'the NC-ization period. A possible drawback to such inducements is that they might encourage firms to buy equipment that they really do not know how to use. They might even incite producers of the equipment to cash in by raising prices.

Another option is the one mentioned above: make Federal financial aid conditional on the fro's getting a competent technical assessment and either following its guidance or working out an alternative plan with the advisor. The obvious difficulty with this option is that adequate public technology extension services don't yet exist.

Tax Incentives

An option much used in Japan is to give companies tax breaks-credits or accelerated depreciation—for investments in new production equipment. Especially prominent are various tax incentives available to small and medium-size enterprises (SMEs). In effect, these tax breaks are subsidies, paid for indirectly by the taxpayers. It has long been Japanese Government policy to encourage business investment with programs that keep the costs of capital low, and this seems to be eminently acceptable to the public, who pay for it. In the United States, policies for this purpose have been less consistent and are much more controversial.

A general discussion of tax incentives as a way to stimulate investments in plant and equipment appears in chapter 3 and an earlier section of this chapter *(Financing Long-Term Investment).* Discussed there are the disagreements among analysts on whether increases in investment due to tax incentives are significant or trivial; the fact that many special tax incentives were removed in the 1986 tax reform act as a quid pro quo for lowering the overall corporate income tax rate; the perverse effect of this bargain, in rewarding old investments

[56]The entire amount of direct business loans and the guaranteed portion of guaranteed business loans disbursed by the Small Business Administration from fiscal years 1953 to 1989 was $50.5 billion, of which $3.9 billion had been charged off as losses by September 30, 1989. On this basis, the loss rate for SBA business loans and loan guarantees was 7,7 percent. (Information provided by the House Committee on Small Business.) However, the "net loss rate," figured on the same basis that commercial banks use, is lower, For1986-88, SBA's net loss rate for guaranteed business loans was 3.60 to 3.74 percent. This compares to net commercial and industrial chargeoffs by banks of 1.17 percent of commercial and industrial loans in 1987 (the latest date available). Note that SBA takes greater risks than banks because its loans go to startups and other good prospects that need long-term loans but have too literal equity or collateral to qualify for a bank loan. Allan S. Mandel, Assistant Deputy Administrator for Financial Assistance, U.S. Small Business Administration, "The Role of SBA 7(a) Loan Guaranty Program in the U.S. Economy," October 1989.

in productive equipment at the expense of new investments; the fact that tax incentives cost something and worsen the budget deficit, unless revenue is found elsewhere to make up for them; and the urgency of weighing all reasonable options for improving manufacturing technology. In view of these many complications and uncertainties, the conclusion was that Congress might wish to mandate a study, with an early delivery date, of the effects of tax incentives as a stimulus to capital investment in manufacturing. This could include a consideration of special tax incentives for small manufacturers.

The broadest and most accessible of the Japanese tax incentives for capital investment by SMEs is accelerated depreciation-14 percent in the first year, on top of normal depreciation-for any machine an SME purchases.[57] A measure more directly targeted to high-tech equipment is the SME New Technology Investment Promotion Tax System (established in 1984) which offers SMEs two options for buying or leasing electronic and mechatronic technology: either a special first year depreciation of 30 percent, or a tax credit of 7 percent of the value of the machine, up to 20 percent of total taxes (in the case of leased equipment, 7 percent of 60 percent of the total leasing expense).

Cooperative Networks of Small Manufacturing Firms

There is strength in numbers. Small firms that band together to do cooperative research and development, get quantity discounts on new equipment, share equipment that no single owner can afford, find out about new technologies and new markets, share orders that are too big for any one firm to handle by itself, and find work for members when orders are scarce, can strengthen themselves and each other without losing competitive drive. Cooperative networks in textiles and metalworking grew and prospered in mid and northern Italy in the 1970s and early 1980s (but seemed to be undergoing some reversal in the late 1980s). Such networks have proven stable in certain industries in Japan, and may be growing in importance.

Both the national and prefectural governments in Japan are strongly supportive of cooperative associations. SME cooperatives can get the same tax breaks and subsidized equipment leasing as individual small firms, and are eligible for low-cost loans from some of the same government financial institutions. There are also special loan programs for cooperatives with low (sometimes zero) interest rates, as well as government support for joint R&D by groups and cooperatives.

Nothing like this government support for cooperative networks of small manufacturing firms exists in the United States. In fact, there is a certain deterrence to cooperation among small firms from antitrust law and enforcement—if not in demonstrable fact, at least in widespread perception (see ch. 7 and the section below on antitrust options.)

If Congress wishes to support the formation of cooperative associations among small manufacturing firms, it might explicitly state that cooperatives are eligible for the technology extension services offered by the Manufacturing Technology Centers. Cooperatives might also be eligible for small business loan guarantees, and if an equipment leasing program is established, for that as well. If Congress wishes to start in a modest way on a program specifically targeted to cooperatives, it might begin with a program of technical assistance on how to organize cooperative activities, such as joint purchases of equipment at discount or shared use of equipment.

Commercialization of Technology From Federal Laboratories

Most R&D performed in Federal laboratories is not directly applicable to civilian industry. Out of $21 billion spent per year, about $13 billion is for defense, and much of the rest is for basic research. Some of this defense R&D and basic research can be made useful to civilian industry, in two ways. First, the labs' expertise and results can be transferred to industry, which then performs further work to commercialize the technology. Technology transfer can be accomplished in many ways, including personnel exchange between labs and industry, private fins' use of specialized lab facilities, and granting licenses to firms for commercializing the labs' patented technology. Generally, effective tech-

[57] Material in this section on tax incentives for SME capital investments is drawn mostly from D.H. Whittaker, "New Technology Acquisition in Small Japanese Enterprises: Government Assistance and Private Initiative," contractor report to OTA, May 1989. This report also provides information on the Japanese equipment leasing and financial aid programs.

nology transfer requires some person-to-person contact.

Second, there is cooperative R&D by the labs and industry. Rather than simply transferring preexisting technology to industry, the labs cooperate with industry to create new technology, which the firms involved can then commercialize. Cooperative R&D builds on the labs' existing work but takes it in a direction useful to industry-helping to bridge the gap between the labs' work and industrial applications.

Cooperative R&D is a powerful tool. With the Federal labs sharing the expense and risk, industry could be better able to take on large, long-term projects with a highly uncertain payoff; and both lab and industry researchers can benefit from sharing ideas with each other. This approach implies that Federal labs should make some of their R&D choices at least partly on the basis of their usefulness to industry.

In some instances mechanisms for promoting commercialization of lab technology have worked well. For example, industry has benefited from using specialized facilities at the Department of Energy's (DOE's) multi-program national labs (e.g., Brookhaven National Laboratory's Synchrotrons Light Source, and Sandia National Laboratories' Combustion Research Facility in Livermore, California). However, there is a consensus among industry, labs, and government agencies that technology from Federal labs with defense or basic research missions is being commercialized much too slowly, despite the legislation that Congress passed throughout the 1980s to encourage such commercialization.

On consideration, this result is not surprising. These types of activities are difficult even when only industry is involved. Firms with much in common have difficulty in agreeing on cooperative research projects, and it is even difficult to transfer technology from a firm's central R&D facility to that firm's own plants. Government-industry interaction is still harder. It requires a fundamental reorientation on both sides, since traditionally the Federal Government and industry have opposed or ignored each other. In particular, the Federal labs and their parent agencies must address many difficult issues involving conflicts of interest, fairness to fins, national security, and proprietary information. Labs also face the formidable obstacle that U.S. firms are often slow to take advantage of new technologies developed outside the firm (see ch. 6). When no firm expresses an interest in a particular technology, it is difficult for the government to identify those firms that could benefit--especially since the government traditionally has not been skilled at marketing. Moreover, even if a lab finds a firm interested in its technology, negotiations can bog down because of bureaucratic inertia and because government agencies often do not understand industry's business constraints.

In the 1980s, Congress encouraged the labs to include technology transfer in their main missions .58 Congress also authorized lab-industry cooperative R&D,[59] but made no special appropriations for it, apparently hoping that it could be supported within existing program budgets. This approach has often foundered, for several reasons. Lab and agency personnel often consider the promotion of commercialization an improper distraction from the lab's primary mission. Agency security offices make conservative rulings on what information can be released, general counsels are equally conservative on which lab-industry arrangements are legally permissible, and these rulings often actively interfere with the labs' efforts to work with industry. And in general, Federal labs and agencies face the inevitable problem of institutional inertia, a serious barrier to the new practices required for improved lab-industry cooperation. Such a climate can stop labs from working with industry unless there is a strong supporting voice within the agency.

Congress could provide stronger incentives for lab and agency personnel to help commercialize technology. In practice, this probably means earmarking money for promoting commercialization. Those who administer such money will want to spend it, and those who spend it will be evaluated on the technology that was commercialized. Congress could also remove some obstacles, including agency

[58]For example, i n the Stevenson-Wydler Technology Innovation Act of 1980 Congress declared the policy that 'the Federal Government shall strive where appropriate to transfer . . . technology . . . to the private sector. In the Federal Technology Transfer Act of 1986 Congress added that "[t]echnology transfer, consistent with mission responsibilities, is a responsibility of each laboratory science andengineeringprofessional." 115 U.S.C. 3710(a).

[59]Federal Technology Transfer Act of 1986, 15 U.S.C. 3710a.

red tape and legal problems with granting exclusive rights.

Earmarking Money for Promoting Commercialization

Most labs (or programs within labs) with missions of either defense R&D or basic research do little cooperative R&D with industry. Congress could mandate that some part of the labs' budgets be spent *only* on cooperative projects with industry-perhaps requiring equal matching funds from industry. A possible model is DOE's high-temperature superconductivity pilot centers in three multi-program national labs, which are collectively spending several million dollars ***only*** on R&D that industry proposes and cost-shares. Congress might start at a few percent of a lab's total budget, and depending on experience increase that amount to perhaps 10 to 20 percent. Since cooperative R&D opportunities must be seized quickly, labs and agencies would need a general pool of money to apply as they saw fit to cooperative projects, without going through a budget cycle to justify each project individually. Congress could also provide stable multi-year funding to give firms the confidence to enter into long-term projects.

Requiring certain money to be spent on collaboration with industry would change the labs' missions somewhat-or at least add to their missions a contribution to the commercial part of the economy. If the labs' budgets were not increased, then their original missions might suffer. However, it might not damage a lab's original mission to choose a small fraction of its research projects on the basis of relevance to industry's interests and needs; some of these projects might still be in some way useful for the mission goals. In any case, Congress might deem it worthwhile to target some fraction of Federal R&D money to projects that have a good chance of leading to commercialization.

Transfer of existing technology to industry also requires money. Activities include identifying appropriate technologies, patenting them as needed, marketing them, and in some cases giving startup firms some support (e.g., office space, help in writing a business plan, access to venture capital) to exploit lab technologies. Congress has directed agencies to set aside 'sufficient funding, either as a separate line item or from the agency's research and development budget" to accomplish technology transfer and to provide annual reports on past and planned technology transfer activities.[60] Congress might wish to conduct oversight hearings to make sure that sufficient funds are being allocated. Alternatively, Congress might mandate required funding levels.[61]

Congress could also increase the funding of the Federal Laboratory Consortium (FLC), currently about $1 million per year. [62]The FLC, with volunteer representatives from over 300 labs and a small central staff, functions for firms as a single point of inquiry or entry into the Federal lab system. Additional full-time staff would help the FLC meet its goal of matching an inquiry with an appropriate lab researcher within 1 day, and would also give the FLC more continuity. With its current reliance on volunteers from the labs, the FLC inevitably suffers from high turnover of personnel. (Full-time staff might be recruited from the labs' ranks; they would then be familiar with the labs.) Additional funding would also let the FLC pursue more projects to demonstrate new ways to facilitate commercialization.

Congress might also designate funds specifically for facilitating personnel exchange. Currently, it is uncommon for industry researchers to take visiting positions at Federal labs, and the reverse is quite rare. Subsidizing visiting positions from a special fund would provide an extra incentive for the firm, the Federal lab, and/or the researcher. The fund could at least be used to ensure that the researcher's pension benefits continue to accrue during his visit.

Removing Obstacles

Before undertaking either to commercialize existing Federal lab technology or to perform cooperative R&D with a Federal lab, firms often require exclusive rights to the technology; otherwise their invest-

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[60]National Competitiveness Technology Transfer Act of 1989, Public Law 101-189, Sec. 3133(e) (amending 15 U.S.C. 3710(b)).

[61]Before the passage of the National Competitiveness Technology Transfer Act of 1989, agencies were directed to set aside one-half percent of their R&D budgets, though agency heads could waive this amount and some did. Stevenson-Wydler Technology Innovation Act of 1980, Public Law 96-480, sec. 11, amended and renumbered as sec. 10 by the Federal Technology Transfer Act of 1986, Public Law 99-502, sees. 3-5,9(e)(l), codified at 15 U.S.C. 3710(I3).

[62]The FLC's complex funding is set out at 15 U.S.C. 3710(e). Funding is set to expire after FY 1991.

ment will not be worthwhile. Labs often face several obstacles in granting these rights.

First, there is red tape while the labs' parent agencies review the agreement. This is a serious problem, since delay can kill a deal. In 1986 Congress permitted agencies to delegate to government-operated labs the power to make agreements for licensing and cooperative R&D (subject to agency veto within 30 days).[63] In April 1987, President Reagan by Executive Order directed all agencies to do so,[64] but it took many agencies until well into 1988 to comply and two (NASA and the Navy) still had not complied late in 1989. Congress might wish to make the delegation mandatory and automatic by statute. In December 1989 Congress passed legislation permitting a similar delegation to contractor-operated laboratories.[65] Congress might also wish to make this delegation mandatory, and/or to conduct oversight hearings to determine whether the situation has improved for DOE's contractor-operated labs, which have often experienced long delays in getting approval for cooperative R&D.

Some of DOE's labs have also been handicapped by having to negotiate with DOE for patent rights before they can grant such rights to a firm. Currently, with certain exceptions, DOE's labs run by non-profit contractors can automatically take title to patents from lab research;[66] Congress may wish to extend that rule to include labs run by for-profit contractors as well, and narrow the exemptions—all with appropriate safeguards such as requiring royalties to be used within the lab.

Another legal problem concerns copyright. Under the law, works created in whole or in part by government employees cannot be copyrighted. This prohibition applies to software created at government-operated labs. Congress might wish to change the law to allow a copyright for such software, so that firms will have more incentive to commercialize software from these labs (commercializing it usually requires substantial further development work) and to engage in cooperative R&D that will produce software. Congress might also wish to clarify that DOE may maintain secrecy for software or other data developed cooperatively.

Lab-industry cooperation raises legal issues not only about exclusive rights, but about many other subjects as well, such as potential conflicts between a researcher's duty to the government and his desire to get personal gain from consulting, royalties, or a contemplated startup firm. To encourage general counsels to overcome their caution, Congress might establish an interagency legal task force for lab-industry interactions. If a general counsel felt uncertain about a proposed arrangement, he could if he wished submit the question to the task force, although the task force's approval would not be required.

University-Industry Collaborations

The National Science Foundation created Engineering Research Centers for several purposes: 1) to integrate different engineering disciplines in R&D projects that are useful to industry and improve U.S. competitiveness; 2) to encourage cross-disciplinary training of engineers; 3) to improve relations between university and industry researchers; and 4) to generate strong participation from industry in research, education, and funding.

Early reports from this relatively new program (begun in 1984) indicate progress toward these goals (see the section on ERCs in ch. 7). In particular, the early returns suggest considerable success in the key objective of educating engineers in several disciplines. NSF is monitoring the centers closely to see that their research is cross-disciplinary, is useful to industry, and gives engineers a broad education. Under this scrutiny, 2 of 18 centers have lost their NSF funding.

The two basic options with a program that seems to be going well are to leave it alone or to expand it. In favor of leaving it alone is the argument the program is still experimental and all the results are not yet in. In any case, the Federal Government is strapped for funds. The strongest argument in favor of expansion is that a bigger program could produce more engineers with the kind of cross-disciplinary training that manufacturing needs. The vast majority

[63] 15 USC. 3710a.

[64] Executive Order 12591, Facilitating Access to Science and Technology, Apr. 10, 1987, sec. 1, par. b(1).

[65] Public Law 101-189, Sec. 3133(a).

[66] 35 U.S.C. 202(a).

of U.S. engineering students take no part in the program.[67]

As noted above, in the section on human resources, one way to increase support for manufacturing R&D and education in universities is to create a Manufacturing Sciences Directorate in NSF. In addition, a much broader program of support for manufacturing R&D in universities might be one of the things a Civilian Technology Agency could do. (See the section below on *Strategic Technology Policy.)*

Tapping Into Japanese Technology

Government-sponsored programs to encourage transfer of technological research from Japan to the United States are of two main kinds: sending researchers to Japanese laboratories (people-to-people exchanges) and scanning the technical literature. Federal programs of both kinds are quite new and still small; they have not yet come near their potential as a source of technological advances. Both would thrive better if more Americans learn to read and speak the Japanese language.

People-to-People Technology Transfer

NSF programs to promote long-term research by Americans in Japanese labs were established by executive action. Congress has not enacted any laws for this purpose, other than including in the 1988 trade act a direction to U.S. negotiators to ensure symmetrical access to technological research.[68] As noted in chapter 7, new government programs to support U.S. engineers and scientists doing long-term research in Japan, established in 1988 by the Japanese Government and the National Science Foundation, were not fully subscribed in 1989-90. There is reason to believe these programs will have many more applicants within a few years, since privately sponsored programs to send researchers to Japan have grown fast after a gestation period of a few years. Congress may wish to monitor the progress of the Japanese government and NSF programs, with an eye to supplementing them if applications multiply and, at some point, expansion is needed.

Meantime, another option would be to establish a Congressional U.S.-Japanese Fellowship Program, taking advantage of the prestige that the sponsorship of Congress confers. Congress might also wish to encourage researchers working in Federal labs to undertake long-term projects in Japan. In oversight hearings, Congress might suggest that agencies encourage sabbaticals for this purpose. For example, the three national labs that have pilot centers working on lab-industry collaborations in high-temperature superconductivity might be able to send some of their people to the Japanese national laboratories, MITI facilities, or university labs that are giving high priority to basic and applied research in this field. A modest but useful initiative that NSF might undertake would be to put together in one place information on all the programs, public and private, that offer U.S. researchers the chance to work in Japan.

In addition, Congress might consider establishing a program of post-doctoral or midcareer commercial fellowships in Japan, open to people other than scientists and engineers, for example, economists, business administration graduates, and experienced business managers. The program might identify positions in Japan that would enrich the fellows' understanding of Japanese management techniques, industry practice, and government-industry relations. For example, positions might be found in Japanese Government agencies, in banks or securities companies (whether Japanese or foreign-owned), or possibly in Japanese manufacturing companies. As with exchanges of scientists and engineers, any such program would have to start small and build gradually as U.S. candidates find out about the program and learn enough Japanese to profit from it.

Scanning Japanese Technical Literature

In the Japanese Technical Literature Act of 1986, Congress took steps to encourage the transfer of technology through the written word. The Office of Japanese Technical Literature, set up under the act in the Department of Commerce, keeps up with new technical developments in Japan and publishes information about abstracts and translations of Japanese technical literature. The office is small,

[67] At four ERCs examined by OTA in visits and interviews, only about 1 percent of engineering undergraduates and4 to 11 percent of graduate students took part in the ERC program. Only 18 universities have ERCs (two of these are being discontinued but two were added in January 1990); this compares with 280 colleges and universities in the United States that offer engineering education.

[68] Omnibus Trade and Competitiveness Act of 1988, Public Law 100-418, Part II., Sec. 5171.

operating with two people on an annual budget of $425,000.

If Congress wishes to take further steps to help researchers penetrate Japanese technical literature, it might wish to increase the appropriation for the office. Possibly, " the office could collaborate with private services that offer abstracts and evaluations of Japanese technical literature and, on demand, translations. Because these services are expensive but not very familiar to potential users, the Office might consider offering users such as NSF grantees or industrial subscribers partial, temporary subsidies. This would get users started, and allow them to judge the value of the services before they have to make full payment.

Japanese Language Studies

The ability to read and speak the Japanese language is fundamental to transferring technology from Japan, both through people and through publications. The best way to learn languages is to start young. Congress has already taken a step toward getting Japanese language instruction in the public schools. The 1988 education act authorized Federal grants of up to $20 million a year to help finance model foreign language programs.[69] The program supports instruction in "critical foreign languages," as defined by the Secretary of Education. Congress might wish to oversee the program and evaluate whether it gives the study of Japanese enough weight.

Congress might also wish to support an expansion of Japanese language programs at the college level and beyond. The NSF language courses for scientists and engineers-are getting an eager response, but are quite small-limited to 100 or so people a year-and are at the post-graduate (mostly post-doctoral) level. One option would be to fund a larger program of this kind. Another would be to encourage the study of Japanese at the undergraduate level, perhaps by providing NSF fellowships for engineering undergraduates who want to study Japanese.

Antitrust Law

Antitrust law has a long and honorable history in this country. It has been used to dismember monopolies (Standard Oil), induce dominant firms to yield entry points to smaller firms (unbundling of IBM computer hardware and software), and open many fields to innovative newcomers. In recent years, however, as international competitors have tightened the screws on domestic fins, some people have questioned whether traditional tough enforcement of antitrust laws is still appropriate or wise.

In fact, antitrust law and enforcement have been relaxed in the past decade. Congress amended the law to make it easier for firms to get together for cooperative research or to form export trading companies. The Reagan Administration was generally considered less aggressive in antitrust enforcement than previous administrations. And the Federal courts have interpreted the law in less stringent ways.

Nevertheless, the antitrust laws may still deter some cooperation among firms that could help their competitive performance. Firms sometimes hesitate to undertake such things as joint R&D or manufacturing, cooperation to set voluntary industry standards, or simple sharing of information, for fear they will run afoul of the antitrust laws. This is especially true of cooperation among firms in the same business. Generally, the problem is not so much that the cooperation would actually violate the law, as that the law is unclear and penalties of misinterpreting it can be severe. Thus, firms often shy away from activity that runs even a small risk of being deemed a violation.

To minimize these effects, Congress could by legislation clarify and modify the legal standard for permissible activities and change enforcement procedures and penalties. It should be possible to draft such changes in the law without letting down our guard against anti-competitive activity. Several bills pending in Congress attempt to strike a proper balance by changing the law in certain limited contexts.[70]

[69] Augustus F. Hawkins-Robert T. Stafford Elementary and Secondary School Improvement Amendments of 1988, Public Law 100-297, Title II, Part B.

[70] These bills include the Joint Manufacturing Opportunities Act, H.R. 423; the National Cooperative Innovation and Commercialization Act, H.R. 1024; the National Cooperative Research and Reduction Amendments Act, H.R. 1025; the High Definition Television Competitiveness Act, H.R. 1267; the Cooperative Productivity and Competitiveness Act, H.R. 2264; the Advanced Television Competitiveness Act, H.R. 2287; the High Definition Television Development Act, S. 952; and the National Cooperative Research Aet Extension Act, S. 1006.

The Legal Standard

One uncertainty in antitrust law is whether an activity will be judged using the rule of reason, under which activities are permissible if pro-competitive outweigh anti-competitive effects. Under the National Cooperative Research Act of 1984,[71] joint R&D (as defined in the Act) is always judged under this standard.

Joint manufacturing, cooperative manufacturing and marketing by small fins, and standard-setting, which in general are more likely to have anti-competitive effects than joint R&D, were not included in the 1984 Act. While the rule of reason would normally be applied to these activities as well, it is not clear that in all cases the pro-competitive effects will be fully considered. Congress could clarify that the rule of reason applies in these contexts as well.[72] This clarification would change the existing legal rules (as interpreted by the courts) little if at all. It would remove doubt as to what the rules are, and (especially if accompanied by congressional findings) would signal courts to take seriously the potential benefits of cooperation.

Congress "could also establish safe harbor market shares, below which no violation would be found. In practice, antitrust violations are now rarely found if the firms involved have a combined market share of under 20 percent. Establishing a safe harbor at that level would not change the law much, but would simplify and clarify it. Firms with less than 20 percent combined market share could proceed without fear; if sued they could get the lawsuit dismissed early on. However, the measure would not apply automatically to all firms claiming to fall below the 20 percent limit; they might still be judged to have a greater combined market share, depending on how the court defined the relevant market.

Antitrust law sometimes makes it difficult for U.S. firms to merge or form joint ventures to resist strong actual or threatened foreign competition. U.S. firms do not get any special lenient treatment in this context, because our antitrust law, as a matter of principle, is nationality-blind (U.S. and foreign firms are treated equally).

Congress might be reluctant to introduce national bias into our antitrust system. Yet even within a nationality-blind framework, antitrust law could be made more sympathetic to mergers or joint ventures of domestic firms under threat of foreign competition. By law, Congress could instruct the Federal enforcement agencies and the courts to take a long-term view and to listen seriously to factual arguments in particular cases that U.S. firms' joining forces will ultimately promote competition in the U.S. market.

For example, it might be argued that foreign firms currently having little share of some particular U.S. market will capture all of it in a few years, unless U.S. firms in the same industry merge or form a joint venture to resist the foreign competition. Although the merger would reduce the number of U.S. competitors in the short run, the number would be greater in the long run--e.g., one instead of none. As a further example, it might be argued in a particular case that competition in the U.S. market cannot be achieved without a healthy U.S. industry. For example, the exit of most U.S. firms from the merchant DRAM market in the mid- 1980s left U.S. computer firms exposed to high prices from foreign DRAM producers. Also, there is some evidence that U.S. computer and semiconductor firms that depend on foreign, vertically integrated competitors for critical components or equipment are last in line for the latest technology.[73] A joint venture or merger that has primarily anti-competitive effects in the near term might be necessary in the long term to maintain a healthy U.S. industry.

Both of these examples involve arguments that U.S. firms in principle can make now in antitrust suits. However, enforcement agencies and courts are likely to reject such arguments as based too much on speculation about the future. Congress could bolster the arguments by writing into legislation: 1) findings that scenarios like those described above can happen, and 2) a direction that the law should be applied to enhance competition in the long term.

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[71] Public Law 98-462, 15 U.S.C. 4301 -4305,"

[72] H.R. 1025 would do so for joint manufacturing and marketing; H. 1024 would do so for joint manufacturing and marketing to exploit R&D conducted jointly or by one or more of the participants; H.R. 423 would do so for joint manufacturing and marketing by small businesses with at most 20 percent combined market share; H.R. 2264 and S. 1006 would do so for joint manufacturing, but not joint marketing.

[73] See ch. 5.

Enforcement Procedures and Penalties

Federal antitrust law can be enforced both by the government and by private parties. Successful private parties are awarded treble damages, plus reimbursement of reasonable attorney fees. These heavy awards in private suits increase the risks to firms undertaking cooperative ventures; in particular, these awards encourage private parties to file lawsuits even when they have weak cases, in the hope of extracting a payment to settle the case.

Some analysts believe that few private antitrust suits are justified and have concluded that private enforcement should be eliminated. However, that would leave enforcement of Federal antitrust law totally up to the Federal Government, which might not have the resources or the will to police the whole country effectively.[74]

A less extreme approach would be to award only single damages in private antitrust suits. This is the provision of Japanese and EC law.[75] Even with single damages, Federal antitrust law would still have stronger enforcement provisions than most other U.S. laws, as it includes both public and private enforcement, attorney fee awards in private suits, and permission to States to sue on behalf of their citizens.

Congress has taken some steps toward removing treble damage provisions. Under the National Cooperative Research Act of 1984, R&D projects (as defined in the Act) registered for publication in the Federal Register are subject only to single damages. Congress is now also considering bills to allow only single damages for registered cooperative manufacturing ventures, registered cooperative manufacturing and marketing ventures, or registered cooperative manufacturing and marketing ventures by small businesses with at most 20 percent market share.[76]

It might make sense to remove treble damages only for projects registered for public disclosure, because anti-competitive activities threaten competition less when they are disclosed to the public. (Treble damages might be needed to discourage firms from secret, clearly anti-competitive activities that might not be discovered. Disclosure enables others to quickly file suitor monitor the project.)

However, selective removal of treble damages might be only partially effective. Some companies might shun registration because it could give away strategic information, and it involves some extra expense as well, including the need to amend the registration if the project's scope changes. If the reduction to single damages covers only certain activities (e.g., as in the bills described above), firms might have trouble predicting whether certain activities are covered. Adoption of single damages for all activities would afford simplicity and certainty, although it could make the law less effective at discouraging some anti-competitive conduct.

A middle ground might be to adopt single damages for certain registered activities and also in individual cases where the accused firm can show it acted in good faith. Good faith might be shown, for example, by an opinion from counsel, or by the fact that the firms had a reasonable (albeit losing) argument that their activity would pass muster under the rule of reason. If treble damages were reserved for the relatively rare egregious cases, the risks of inter-fro cooperation would be less, and private parties would have less incentive to file suit with weak cases.[77]

Another option, which could complement the single damages approach, is to let firms apply to the government for advance certification that a proposed activity is permitted. The Export Trading Company Act of 1982 followed this approach for export trading companies.[78] One bill before Congress takes this approach for joint manufacturing and marketing that exploits R&D results.[79] So long as firms stay within the scope of the certification, they could not be sued for damages or penalties, either by the

[74] See for example, *Report of the American Bar Association Section of Antitrust Law, Task Force on the Antitrust Division of the U.S. Department of Justice,* July 1989, pp. 52-55 (finding that the Antitrust Division of the Department of Justice has inadequate resources and low morale).

[75] Thomas Jorde and David Teece, "Innovation, Cooperation and Antitrust: Balancing Competition and Cooperation, ' *High Technology Law Journal,* vol. 4, No. 1, spring 1989, p. 56 and footnote 157. EC antitrust law applies only in certain circumstances; in other cases, the member states' own antitrust laws apply.

[76] H.R. 2264 and S. 1006, H.R. 1025, and H.R. 423, respectively.

[77] A similar rule exists for patent infringement. Treble damages maybe awarded, but only in egregious cases.

[78] Public Law 97-290, 15 U.S.C. 4001 et seq.

[79] H.R. 1024.

government or private parties. At most, they could be ordered to stop what they were doing.

Advance certification gives greater protection to firms than just replacing treble with single damages, but could be costly and time-consuming. Present procedures for non-binding approvals from the Justice Department and the Federal Trade Commission often take several months and require considerable attorney time. Certification would be most useful if, at least in simple cases, a firm could apply for one without assistance of counsel, and it could be issued within weeks, not months.

Innovation and Intellectual Property

Many concerned with our manufacturing competitiveness would put stronger intellectual property protection worldwide for new technology (including patents, copyrights for software, and trade secret protection) near the top of their list. Stronger protection, it is argued, rewards invention, which is an American strength, and by encouraging R&D would make U.S. products more competitive. Also, it would discourage foreign firms from imitating U.S. firms' new products and processes—thus protecting sales of U.S. firms, making them stronger competitors in the present and better able to support long-term development for the future.

It is not clear, however, that stronger protection always encourages more R&D. And it is not clear how much stronger protection would help increase U.S. fins' sales. There are limits, for example, to how far we can push developing countries to go along with stronger protection, since they do not see it as to their advantage. From their point of view, it would make their people pay more for foreign goods and stop their firms from taking advantage of foreign technology. More fundamentally, patents and other forms of protection for technology usually provide only a temporary edge, until competitors find or invent an alternative way to get the job done. A surer way to competitive success over the long run is to improve the cost and quality of U.S. manufactured goods.

Nevertheless, some changes could improve the intellectual property environment. First, certain features can be corrected in the United States-a relatively easy thing to do, since it can be done unilaterally. These improvements at home matter since the United States remains the most important market for most U.S. firms today. Measures requiring international negotiation can also be usefully pursued. These concern not only the substance of legal rights but also the procedures for enforcing them. If intellectual property law is poorly enforced, then even strong-sounding legal rights do not amount to much in practice.

Protection of Patent Rights in the United States

Prompt enforcement of patent rights is the most urgent need for improvement of intellectual property protection in the United States. Patent cases that go to trial take an average of over 21/2 years before ending in a decision. During this time the firm with the patent loses sales and must pay legal bills. Some firms might not make it to the end of the trial. Even if a firm survives and prevails at trial, compensation awarded by the court might not fully makeup for the harm caused by the infringer. (However, recent court decisions show particular concern to provide full compensation when possible, and also show willingness to find special circumstances justifying treble damages or an award of attorney fees.)

One way to speed up patent infringement trials would be to designate special judges for patent cases. At present, patent cases are normally heard by U.S. district court judges, who often have little expertise in patent law. Congress could encourage or require district courts to designate certain judges to hear all patent cases. They could be chosen for their expertise in patent law or build it up with experience.

This approach would conflict with the philosophy that Federal judges should be generalists. However, specialist Federal judges are not without precedent. Since 1982 the U.S. Court of Appeals for the Federal Circuit has handled all appeals in cases arising out of patent law and in certain other specialized areas of the law since 1982. That court is credited with bringing order and predictability to patent law. Because patent law is hard for the uninitiated to grasp, it seems a good area of the law for specialist judges. (If the Federal Circuit is any guide, specialist judges also tend to favor patent owners.)

Congress might also consider increasing the judicial manpower devoted to hearing patent cases. One option might be to increase the number of Federal district court judges across the board (with the option of designating some of them patent judges); alternatively, Congress might instruct the courts to advance patent cases ahead of other cases. However, our Federal judicial system in general

suffers from delay, and Congress might not believe that patent cases need extra judges any more than, for example, cases against drug dealers do.

In evaluating whether patent cases deserve a special claim on limited judicial manpower, Congress might consider that, in effect, extra judges have already been assigned to hear patent cases, and those judges' ability to handle cases quickly and competently has been hailed as a great strength of our patent enforcement system. These are the four administrative law judges at the U.S. International Trade Commission. They are assigned to hear cases of "unfair imports" under Section 337 of the Tariff Act of 1930, as amended,[80] most of which concern patent infringement. Under Section 337, U.S. firms can apply for an order to be enforced by the Customs Service which stops infringing goods from entering the country. The law mandates that cases be decided in 1 year (18 months in a minority of cases declared "more complicated' ')—much faster than the average time for trial in Federal district court.

However, the General Agreement on Tariffs and Trade (GATT) ruled in 1989 that Section 337 enforcement proceedings violate U.S. obligations under the GATT treaty, by discriminating against foreign goods. This decision put pressure on the United States to change Section 337 procedures. However, it is hard to satisfy the objections of the GATT panel while keeping the advantages of: 1) a quick decision, and 2) an order which can exclude all infringing goods (or all infringing goods from certain manufacturers), no matter by what route and by whom they are imported. The Office of the U.S. Trade Representative has been considering various options, including handling all patent infringement cases in a special court, or allowing the Commission to issue temporary exclusion orders which would then be reviewed by a court with a full trial. The Administration may propose a solution along these or other lines for consideration by Congress.

Protection of Patent Rights Abroad

The United States is engaged in bilateral and multilateral negotiations to strengthen intellectual property protection abroad. Two important goals are changes in Japan's patent system and a unified world patent system.

U.S. firms find Japanese patents not very effective in stopping imitation by Japanese firms. Japan's system is slower than ours in issuing and enforcing patents, and it is strongly tilted toward licensing of patents (see ch. 7). Often, U.S. firms wish *not* to license patents to Japanese firms but rather to exclude them. The reason is fear of losing all their sales in Japan, since Japanese customers strongly favor a Japanese supplier if one is available. Successful negotiations to change the Japanese patent system could help some American firms hold on to sales in the rich and fast-growing Japanese market.

Besides the problems inherent in the Japanese patent system, there is the added problem that many U.S. firms are ignorant of how the system works. This ignorance sometimes extends to basic facts. For example, one firm did not know that after the initial application, a follow-up request must be made for the Japanese patent office to examine the application. Congress might consider creating an office in the Patent and Trademark Office to collect and disseminate information about the Japanese patent system.

The second goal, creation of a unified world patent system, would help firms desiring patent protection in more than one country. Currently, with some exceptions, they must file separate applications in each country. This is expensive, requiring legal and translation services in each country. In an international patent system, one application would be enough for a patent good in all participating countries.

A prelude to this long-term goal is the harmonization of different countries' patent laws and application procedures. The United States has been negotiating to this end, especially with Japan and the countries of the EC. Any agreement will probably require substantial changes in our own patent system. For example, the United States now follows a first-to-invent system (in which the first person to make an invention is entitled to a patent); we would probably have to change to a first-to-file system (in which the first inventor to file an application is entitled to a patent), which almost all other countries now use. Also, the United States now keeps patent applications secret; almost all other countries publish applications after 18 months. In this too we

[80] 19 U.S.C. 1337.

would probably have to follow suit. While such changes might face strong political opposition in this country, Congress may wish to consider them seriously if they are proposed by the Administration as part of an overall treaty, containing important concessions from other countries.

STRATEGIC TECHNOLOGY POLICY

In the past 40 years, and especially in the last 10, it has been an article of faith that government support of research and development should stick to basic science, or else to the government's own needs—mainly military security. Yet, government backing for particular technologies seen as critical to the nation's economic progress is hardly unknown. The most obvious example is in agriculture. The U.S. Government contributes well over $1 billion a year to the Cooperative Extension Service for agricultural research and technology extension. The Service itself is 75 years old, and its origins go back still further, to the foundation of the land-grant universities in the Merrill Act of 1862 and Federal finding of State agricultural experimental stations, begun under the Hatch Act in 1887.

A venerable example from manufacturing is the civilian aircraft industry. Established in 1915, the National Committee on Aeronautics (NACA, later the National Aeronautics and Space Administration, or NASA) conducted or funded significant research on airframe and propulsion technologies for years. NACA's R&D typically went well past basic research, extending to pre-commercial proof of concept (tests of specific combinations of materials and systems). The government's decision in 1915 to back the aircraft industry with scientific and engineering R&D was grounded in the conviction that the entire nation had a stake in all phases of aviation, and that the country where powered flight was invented should be a leader in its continued development. The decision was made on patriotic, but not narrow national security grounds.

After World War II, the idea took firm root that only defense needs justify government development of new technologies much beyond the basic research stage. Although the government was the principal force in the early development of computers and semiconductors, both through R&D funding and procurement, it did so in the name of defense.[81] Sometimes the connection with defense was indirect. The Defense Advanced Research Projects Agency (DARPA), whose mission is to support long-term, risky research for national security needs, justified some of its computer R&Don the grounds that, since the Department of Defense was a major user of computers, it would benefit in the end from R&D that led to advancement of the technology in the commercial sector.

A related argument was used recently to justify the special government funding that semiconductor R&D is receiving. Alarm over the precipitous loss of the memory chip market to the Japanese led to urgent requests from U.S. semiconductor producers for government R&D help. Congress responded with a contribution of $500 million over 5 years to the Sematech consortium to improve the manufacture of DRAM chips, and put DARPA in charge of the government's part in the project. The idea is that military security depends on a stable supply of memory chips from U.S. suppliers. Congress also gave DARPA a total of $46 million in fiscal years 1988-89 for R&D in materials, devices, and manufacturing process technology for high-temperature superconductivity.

The national security argument is wearing thin, however. As the military threat from the Soviet Union recedes, the economic challenges from Japan, the newly industrialized Asian countries, and a unified Europe loom larger than ever. In the public debates on government support for Sematech, high-temperature superconductivity, and lately on high--definition television (HDTV), the stakes in economic as well as military security got some frank recognition. Not all parties agreed that our economic security needs any bolstering from the government. But the stage was set for a new debate in which the grounds for public support of technology advance could shift.

Picking Winners

Government funding for R&D in semiconductor technology, high-temperature superconductivity, and technologies for HDTV departs from usual U.S. policy since each of these projects concentrates much more on the applied than the basic end of R&D. Indeed, the whole point of Sematech is to

81 Kenneth Flamm, "Government's Role in Computers and Superconductors," contractor report to the OTA, March 1988.

improve the manufacturing process for a particular product—the 16-megabit DRAM semiconductor. However, the recent cases are tentative and ad hoc compared to the steady long-term R&D support that civil aircraft manufacture has enjoyed, and the combination of R&D and technology extension that has been available to American agriculture since early in the century, through the land grant colleges and the Cooperative Extension Service.

The widely accepted economic argument for selective but solid government support of commercially interesting technologies is that government should share the risks of long-term, highly uncertain R&D projects in which the potential for benefits to society is great, but the payoff to individual firms is likely to be small and not worth the risk. In the U.S. financial environment, with its high cost of capital and emphasis on short-term profit taking, the argument for government's sharing the risks of long-term R&D takes on special force.

The argument against giving selective support to technologies that are vital to particular commercial industries is mostly political. In brief, it runs as follows: the American political system is pluralistic, disorderly, and open at so many places to influence from special interests that rational government decisions on technology or industry policy are next to impossible. The idea that government cannot "pick winners,' and if it tries to will just bungle the job, rests partly on this political argument and partly on the simple claim that the market, for all its failures, is a better bet.

Politics probably interfere less in government support for R&D than in ventures more directly connected to commercial production, such as government-backed low-cost loans or purchase guarantees. Such ventures are likely to cost more than R&D support, and are closer to the intensely political issue of jobs. Moreover, it is possible to erect safeguards against ill-informed or political] y inspired choices of technologies for government R&D support. Shared R&D projects, in which industry takes part in selecting the subject and puts up at least half the money, are one way for government to escape blatant pressure from special interests and also to enlist industry and market forces in the process of picking winners.

The record of the two industries that have received most government support for technology advance over the years belies the simple statement that government cannot pick winners. These industries can hardly be described as failures. Until the recent challenge from Airbus (which has had billions of dollars in R&D *and* working capital support from four European governments) the U.S. air transport industry was the undisputed world leader in technology, and it still produces a bigger trade surplus for the United States than any other manufacturing industry ($15.4 billion in 1988). Agriculture has contributed trade surpluses for years ($16.4 billion in 1988) and is a technology leader as well. Labor productivity on U.S. farms has increased more than elevenfold in this century .82

The history of both industries suggests that government can not only pick winners but help to create them. (See box 2-A for a brief account of government support for the civilian aircraft industry.) Of course, there are failures too. For example, in 1980 Congress voted to create the Synfuels Corporation that President Carter had proposed the previous year, providing $20 billion in loan guarantees for plants making wood-based, coal-based, and shale-based substitutes for petroleum fuels, and price guarantees for the output. Synfuels was one of several initiatives designed to make the United States energy-independent, some of which still continue today. But expectations that the Synfuels Corporation would be able to produce fuels from domestically available feedstocks without additional research and development were unrealistic, oil prices fell, and the Reagan Administration succeeded in killing the program. Synfuels, it is generally conceded, was a failure.

Japanese industrial policies have missed the mark too. Some examples of projects that did not achieve their objectives include MITI's effort to spur fast development of the biotechnology industry, the fifth generation computer project aimed at developing artificial intelligence, and the entry into the civilian

[82] Some agricultural technologies developed and disseminated by the Department of Agriculture, the land grant universities, an the Cooperative Extension Service have raised labor productivity at serious cost to other values. For example, the overuse of broadscale persistent insecticides in the 1950s and 1960s did much environmental damage, and in the end did not work because the target insects became resistant, secondary pests were released, and natural predators were killed off. However, continuing R&D in the Federal-State agricultural research and extension system is working on safer approaches to pest management.

aircraft industry with the YS-11 commercial transport.

Thus, there are examples of both success and failure. The failures do not prove that government is inherently ineffective at fostering technologies of interest to particular industries. Said one DARPA employee, "We defend our right to fail." This is an essential right for anyone trying to develop something new, whether it is new to the world, like aircraft in the early 20th century, or new to a nation, like a commercial air transport industry was to Japan in the 1950s.

Another lesson may be learned from our limited and uneven record of picking commercial winners; that is, if efforts are confined to crisis situations, they will be more likely to fail than if a more proactive, strategic approach is adopted. Synfuels was conceived in 1979 when, for the second time in the decade, oil deliveries from the Middle East were sharply curtailed for political reasons, prices shot up, shortages appeared, and anxiety over energy dependence was at a peak. Today, there is an air of urgency over whether or how to support America's late entry into the business of developing and producing advanced television products. In a panic situation, there is little time to construct or examine options or weed out the wilder ones.

Creating a Civilian Technology Agency

One option to help avoid the pitfalls of technology development by crisis is to establish a civilian technology agency. The last few years have brought arising chorus of pleas by and on behalf of industries that are in danger, and it is likely there will be more in the future. If Congress wishes to respond to those pleas in an organized fashion, it could benefit from having an agency whose job would be to anticipate such developments, develop proactive options in response, avoid some crises, and improve the chances of responding well when they do arise. The alternative is for Congress to continue responding ad hoc—an option that some prefer, on grounds that government support for commercial R&D should be the exception, not the rule.

Congress has already established a small program that might in time become a full-fledged civilian technology agency—NIST's Advanced Technology Program. Created in the 1988 trade act, the program got its first funding, $10 million, in fiscal year 1990. The Program's purpose, as stated in the law, is to help U.S. businesses apply research results to the rapid commercialization of new scientific discoveries, and to the refinement of manufacturing technologies. The Program can assist joint R&D ventures with technical advice or can take part in them—providing start-up funding or a minority share of the cost, or lending equipment, facilities, and people to the venture.

In October 1989, the Senate passed a bill that would authorize the Advanced Technology Program to receive as much as $100 million funding per year and gave quite specific directions on where to put this R&D support.[83] The bill directed the Program to give limited financial assistance to industry-led joint R&D ventures in "economically critical" areas of technology, and spelled out five areas that should get most of the support: advanced imaging electronics, including advanced television; advanced manufacturing; applications of high-temperature superconducting materials; advanced ceramic and composite materials; and semiconductor production equipment for the development of X-ray lithography.[84]

Other bills in the 100th and 101st Congresses, taking a broader but less directive approach for R&D support of strategic commercial technologies, proposed to create an Advanced Civilian Technology Agency .85 It would be located in a new Department of Industry and Technology, replacing the Department of Commerce. The agency would make grants to and cooperative agreements with R&D entities, with the government providing a minority share of the funding. The purpose would be to support high risk projects with potentially great value to the civilian economy that would otherwise lack ade-

s3s. 1191, entitled the Technology Administration Authorization Act of 1989.

84The bill specified that $75 million of the $100 million should be available for these five areas, with individual projects to be approved by the Secretary of Commerce and the Director of NIST; in reporting the bill, the Senate Committee on Commerce, Science and Transportation suggested specific amounts for each of the five high technology areas. The bill also authorized $13 million for other technologies deemed of great economic importance by the Secretary and the Director; $10 million was reserved for small businesses with promising technologies; and $2 million was specified for program management, analyses, and workshops.

85One of these bills, S. 1233 in the 100th Congress, was reported out of the Senate Committee on Governmental Affairs, attached to the 1998 trade act, and then dropped. Two similar bills, H.R. 3838 and S. 1978, were introduced in the 101st Congress.

Box 2-A--Government Backing for the Civilian Aircraft Industry

After the Wright brothers flight at Kitty Hawk in 1903, the U.S. Government was slow to get behind aeronautical research and development.[1] Twelve years went by before the creation of the National Advisory Committee for Aeronautics (NACA), a U.S. Government institution whose purpose was to further the science and technology of aeronautics. Meanwhile, the Wrights (and some others, mainly Glenn Curtiss) had gone on building planes and improving them, but with little research support. Most of the flying was left to barnstormers and stunt flyers, whose hijinks and appalling safety record did not help to commend aviation to serious research attention. The military services waited until 1907 to let their first contract for an airplane, and the first appropriation for military aircraft-$25,000 for the Navy-came in 1911.

At the same time, European governments were taking very seriously the possibilities opened up by the first successful powered flight. All over Europe, but particularly in France, Britain, and Germany, governments either established or contributed to aeronautical research centers. Advances came quickly. In July 1909 Louis Bleriot flew across the English Channel. In the next couple of years, many new European planes emerged (Bleriots, Farmans, Antoinette), some demonstrating features such as allerons and monoplane design that were superior to the Wrights' designs,

Aviation enthusiasts in America were mortified. They "found it a national embarrassment-not to say a danger--that the country where aviation began should trail so far behind the Europeans."[2] By 1911, some of them started to campaign in earnest for a national aeronautical laboratory. They were not to succeed until 1915, when Theodore Roosevelt endorsed the idea and the Congress looked on it with favor. Even so, the joint resolution creating NACA would have been lost in a close-of-session rush if it had not been backed by the powerful Naval Affairs Committee and tied to a navy appropriation bill.

NACA's charge was to ''supervise and direct the scientific study of the problems of flight, with a view to their practical solution, and to determine the problems which should be experimentally attacked."[3] By the 1920s, NACA was an important contributor to R&D for the fledgling commercial industry. NACA pioneered in building and using large wind tunnels, collaborated with both the civilian aircraft industry and the military on designing research projects, and made its test facilities and a stream of test results available to both throughout the 1920s and 1930s.

NACA boasted among its accomplishments the design, modeling, and testing of a family of airfoil shapes, so well-characterized that designers could select wing sections for various purposes off the shelf. The famous NACA cowl, developed and tested in NACA's propeller wind tunnel in the late 1920s, was credited with greatly reducing wind resistance in the then-standard air-cooled radial engine, cutting engine drag by 75 percent with hardly any loss in cooling. NACA research also helped to define optimal placement of the engine in the wing, thus contributing to much greater engine efficiencies and higher speeds, When airline cruising speeds rose from 120 to 180 miles per hour, overnight transcontinental runs became possible, and air travel boomed even in the midst of the depression.[4]

After World War II, NACA and its successor, the National Air and Space Agency (NASA) continued aeronautical research and testing, but the aircraft companies were soon outspending them, and military R&D dwarfed both.[5] However, the aircraft companies continued their close relations and collaborative research with NASA, and a liberal system of cross-licensing of patents (originally backed by NACA and continued under NASA) helped to diffuse technology advances throughout the industry.[6] Technological spillover from military to civilian aircraft remained consequential at least through the 1960s. For example, the airframe design of the Boeing 707

1 Alex Roland, *Model Research: The National Advisory Committee for Aeronautics, 1915-1958* (Washington, DC: U.S. Government Printing Office, 1985), vol. 1.

2 1bid., p. 4.

3 Public Law 271, 63d Cong., 3d sess., Mar. 3, 1915, cited in Roland, Op. Cit., vol. 2, p. 394.

4 Roland, op. cit., vol. 1, pp. 92-94, 111-116; David C. Mowery and Nathan Rosenberg, 'The Commercial Aircraft Industry,'' *Government and Technical Progress,* Richard R. Nelson, (cd,) (New York, NY: Pergamon Press, 1982), pp. 128-129.

5 From 1945 to 1984, total R&D spending in the aircraft industry, military and civilian, was $109 billion (1972 dollars), of which $81 billion was provided by the military, $18 billion by industry, and over $9 billion by non-military Federal agencies. David C. Mowery, "Joint Ventures in the Commercial Aircraft Industry,''*International Collaborative* Ventures *in U.S. Manufacturing,* David C. Mowery (cd.) (Cambridge, MA: Ballinger Publishing Co., 1988), p. 75, For a brief history of government R&D support for the civilian aircraft industry, see David C, Mowery, "Collaborative Research: An Assessment of Its Potential Role in the Development of High Temperature Superconductivity," contract report to the Office of Technology Assessment, January 1988.

6 Cross-licensing was abandoned in 1975, due to the objections of the Antitrust Division of the Department of Justice,

passenger plane was such a clone of the KC-135 refueling tanker that Boeing made for the Air Force that the first prototype 707 wheeled out of the Seattle plant had no windows in the fuselage.[7] Boeing eventually made more than **800 KC-135 tankers.** Sharing development costs and moving down the learning curve together with its military twin brought down costs for the 707 much faster than would have been possible otherwise.

The civil aircraft industry also benefited from other government policies besides NACA/NASA support for R&D. From 1930 to 1934, U.S. Government contracts with airlines to carry the mail included subsidies, and helped to sustain demand for civilian aircraft during the depression. (Indeed, at that time, the major aircraft companies were vertically integrated with the airlines and with engine companies as well. The Air Mail Act of 1934 ended the subsidies and forced dissolution of these vertically integrated firms.) In addition, regulation of airlines by the Civil Aeronautics Board indirectly favored technology advance in aircraft manufacture. By ruling out price competition, the CAB encouraged the airlines to compete on performance instead, and thus indirectly supported the aircraft manufacturers' commitment to technological excellence.[8]

CAB regulation is now ended; the airlines are competing more on price and passing on competitive pressures to aircraft manufacturers. And the civilian aircraft industry relies less than it did in the past on government R&D. The airframe companies-especially Boeing, which is far and away the biggest in the civil aircraft business---fund most of their research and nearly all their development costs on the commercial side (engine companies still get substantial Defense Department funds for commercial projects that may have a military payoff).[9] Also, spinoffs are fewer; civilian and military aircraft technology has increasingly diverged in the past 20 years or so, not only in the overall product but to some degree in component technologies.[10] Nevertheless, NASA still spends a fair amount on generic aeronautical research and testing (about $350 million to $400 million a year), which complements the industry's private R&D and reduces its costs to this day.

7 Mowery and Rosenberg, op. cit., p. 131.

8 Mowery, "Collaborative Research," op. cit.

9 MIT Commission on industrial Productivity, "The U.S. Commercial Aircraft Industry and Its Foreign Competitors," *The Working Papers of the MIT Commission on Industrial Productivity* (Cambridge, MA: The MIT Press, 1989), p. 16.

10 Ibid., p. 17.

quate private support. The agency's activities would be overseen by a 21 -member Board with at least 14 from various industries and businesses, small and large, and the rest from State and local governments, academic institutions and nonprofit organizations.

A model that has sometimes been suggested for a civilian technology agency is DARPA. Established in 1958 (as ARPA-the D, for Defense, was added later), this small elite agency has gained a reputation for flexible, impartial decisionmaking, and for intelligently placing its bets. It has of course, lost some of its bets, and some have been a very long time in paying off. For example, from its beginning DARPA has been a major supporter of research in artificial intelligence. Only in the early 1980s, after 20 years of steady investment by DARPA, did the first commercial AI projects begin to emerge.[86]

It may be objected that DARPA is not appropriately compared to a civilian technology agency, since it has a military mission and can be held accountable to that mission. Yet, as noted above, DARPA has often interpreted its mission very broadly. The Department of Defense buys on the commercial market, and it benefits if that sector excels in technology, and suffers if it lags. And if the commercial sector does lag, U.S. defense could become too dependent on superior foreign producers. The fact that commercial companies are selling AI machines based on research that DARPA has funded for nearly 30 years illustrates how DARPA's broad interpretation of its mission can carry it well into the commercial side of the economy. (This is not always the case; DARPA's support for broad R&D projects with no obvious short-run military applica-

86 The first commercial AI machine was Xerox's Interlisp work station, introduced in 1981. Although Xerox funded much of the development internally, it also relied on DARPA projects and funds. By 1985, four U.S. firms were selling computers designed to program in the AI language LISP; all had direct ties to DARPA-funded research. Flamm, op. cit.

tions has waxed and waned, depending on budgets and competing DoD demands.)87

The parallels between DARPA and a civilian technology agency go only so far. Choosing technologies that must eventually prove their worth in the market is tougher, even allowing for failures, than choosing ones for which there is some credible military use, so that at least one customer—the government-is likely to materialize. Also, the choice of technologies to support may lend itself to political pressure on the civilian more than on the military side (though decisions about military procurement are hardly free from the competing claims of different regions and industries). A civilian agency would probably have to balance political pressures more deftly than DARPA is called upon to do, but the difference might be more a matter of degree than of kind.

A distinct difference is that a civilian technology agency would need to interact much more closely with industry than DARPA does in choosing technologies to support, in the design of R&D, and in joint payment for R&D. Until very recently, with Sematech and some small HDTV projects, DARPA has not funded projects jointly with industry. And DARPA staff members exercise a great deal of independent judgment about what technologies to fund.

Perhaps the biggest threat to the long term success of a civilian technology agency is exaggerated expectations. Technology push, even if planned and directed intelligently, certainly does not guarantee successful commercialization. One reason for the continuity and accomplishments of NACA/NASA support for the civilian aircraft industry is that it was low-key and did not promise miracles. To restore world-class performance in U.S. manufacturing industries will take much more than selective government support for technologies up to the point of commercial production. Technology push is just one of the many things that must be done, by industry and government alike.

Designing a Civilian Technology Agency

Any Civilian Technology Agency (CTA), whether it develops from the NIST Advanced Technology Program or is established more formally, would certainly start small, and might remain so. DARPA has a staff of 150, half of them in technology development and the other half in administration, and about $1.3 billion a year to spend on R&D projects. Too much smaller, and the agency would not have a critical mass. Too much bigger, and it probably could not operate in the anti-bureaucratic way DARPA does, which is to give each member of the technology staff almost total responsibility for the areas he or she manages.

After a few years' experience, a CTA might take over some technology projects from other agencies, such as engineering projects of the National Science Foundation (e.g., the Engineering Research Centers). But most of the big government technology programs now in existence are solidly ensconced in their present homes (NASA, DOE labs, National Institutes of Health). If a CTA were to grow, it would more likely result from years of success and expansion in its own line of work than from reshuffling present programs. The bills in the 101st Congresses to establish an Advanced Civilian Technology Agency in a new Department of Industry and Technology propose a small agency, starting with a staff of 40 (primarily recruited from industry, on temporary assignment) with a first year authorization of $100 million, rising to $240 million in the third year.

A small agency funding technology R&D probably works best if the staff members are not hemmed in by too many rules and guidelines, but can exercise their own good judgment. DARPA attracts its excellent staff by offering a combination of hard work, low pay, great responsibility, and a chance to do something for one's country. If a consensus develops that the foremost job for the Nation is to secure our economic future, the chances would be good that a CTA could hold out similar attractions—with the difference that the staff would work much more cooperatively with industry. One caveat: the low pay (relative to private jobs) that government can offer to highly trained scientists and engineers has not stopped DARPA from getting good people, though they tend to leave when their children reach

[87] For example, during the heyday of the Strategic Defense Initiative in the 1980s, DANA cut back on its support of broad advances in computer technology in favor of the Strategic Computing Program, which was a part of SDI. Funds were diverted from universities responsible for the earlier programs (and their eventual success) to military contractors. The emphasis changed from long-term open-ended results to milestones and concrete deliverables.

college age. Low pay could be a greater handicap to a new agency just starting out.

Where in the government bureaucracy a CTA is located may not matter much. Aside from the President's own staff and the upper reaches of the Office of Management and Budget, power in the executive branch of the Federal government is fairly dispersed. It is probably an advantage to the National Science Foundation to be independent of any department. Yet DARPA, a tiny appendage to the biggest and most hierarchical of all the Federal agencies, still makes its voice heard through sheer competence and dedication.

Defining Goals, Choosing Projects

Desirable as it may be to give the CTA management and staff freedom from red tape in working with industry and choosing technologies for support, some explicit overall goals should serve as a framework for the choices. If Congress wishes to establish a CTA, it might give the agency the duty of developing a set of goals, based on a more general mission defined by Congress. For example, proposals before the 101st Congress for a CTA defined its mission as contributing to U.S. competitiveness by ''supporting generic research and development projects . . . that range from idea exploration to prototype development and address long-term, high risk areas . . . that are not otherwise being adequately developed by the private sector, but are likely to yield important benefits to the nation."[88] Similarly, S. 1191, the bill passed by the Senate in 1989 that aimed to beef up NIST's Advanced Technology Program, referred to "research that no one company is likely to undertake but which will create new generic technologies that will benefit an entire industry and the welfare of the Nation. In defining the mission, it would be unwise to limit the support only to long-term, high-risk technologies with supernova potential. This could rule out catch-up projects like Sematech, or projects for incremental improvements in technologies that are already well-known, such as a next-generation controller for machine tools.

The "visions" that Japan's Ministry of International Trade and Industry develops in consultation with industry for Japan's economic development offer an example of goals that a CTA might advance. MITI's current vision is for a knowledge-intensive economy. This means support not only for technologies important to Japanese industries that are obviously knowledge-intensive themselves (e.g., computers) but also projects that deepen knowledge intensiveness in traditional industries (e.g., the Automated Sewing System, a 7-year $90 million MITI project that brought together 28 textile, apparel, and textile-apparel machinery manufacturers in a cooperative R&D effort).

How the government's fund should be divided among various broad areas of technology is the most fundamental of the choices to be made. How much—if any—should go to high-temperature superconductivity? How does high-temperature superconductivity compare with competing claims for technologies important to computers, or advanced television, or industrial robots, or advanced automobile engineering? S. 1191 was specific in directing NIST to support technologies in five particular high technology areas. The bills aiming to create a CTA was less directive, leaving it to the agency to make these choices, with the guidance of its advisory board. Thus, the CTA would have to pick winners; that would be the nature of business. While the agency would have the final responsibility for deciding how government money should be spent on technology R&D, it would rarely choose to support a technology that did not also have strong industry backing, including a financial commitment.

Another point is that a CTA would need to consider whole technological systems rather than isolated bits of systems. For example, if (as is quite likely) it should select semiconductor technologies, it would have to be mindful of R&D needs throughout the system, starting with improved materials for the silicon crystals that are made into wafers, and continuing through such things as X-ray lithography for etching circuits on the wafers (including the whole paraphernalia of a source for the X-rays, lithographic equipment, photochemicals, masks and substrates); automated techniques for packaging chips; advanced methods for placing chips on a board and interconnecting them; and so on. As part of its strategic approach, the CTA should also look for technologies that are central to more than one application. Examples are advanced displays and the technologies for manufacturing them, applicable to both HDTV and computers; high-temperature super-

[88] H.R. 3838 and S. 1978, part B—Advanced Civilian Technology Agency, Sec. 212(a).

conducting magnets, which could be important for several steps in semiconductor manufacture (e.g., compact synchrotrons as a source of X-rays for lithography) as well as for such futuristic things as magnetically levitated trains.

Once a technology is selected for support, the choice should be given a fair chance. Just as the CTA could provide a way to look ahead and make strategic choices rather than react to the technology crisis of the day, it could also impart steadiness. Continuity-a long-term, multi-year commitment—may be the most important benefit government has to bestow on a risky undertaking.

Government-Industry Collaboration

The main reason for government to put money into technology R&D of commercial interest is that the risks are too great for individual companies to bear. But if private companies are not interested enough to take some of the risk and do some of the work, then the commercial potential may be very remote. It might make sense for a CTA to reserve a small portion of its funds for projects that are so long-term and chancy that they do not attract much industry support. But for the most part, if industry is not willing to pay a hefty portion-usually at least 40 to 50 percent—the projects are probably not worth pursuing. Other requirements for member companies could be willingness to put well-qualified employees on the project, carry on complementary research, and make a fairly long-term commitment, say 3 years.[89]

In the few collaborative projects that the U.S. Government has recently proposed or undertaken, industry participation has been no problem. All have had enthusiastic takers. In the case of Sematech, it was the semiconductor industry that did the proposing; the industry lobbied hard for the program. Member companies pledged to contribute 1 percent of their revenues, and they are paying about half of the costs. The three national laboratories with pilot programs for R&D leading to commercialization of high-temperature superconductivity have cooperative agreements with two dozen companies, all paying half the costs of their projects, and still more companies want to join if the labs can find enough matching funds. When DARPA proposed to put up $30 million for collaborative R&D projects in HDTV 87 companies wanted in.

Sematech has its own facilities, but some government-industry collaborative R&D could take place in the company labs. Much more could be done in Federal labs, especially the Department of Energy's well-endowed national labs. (See the discussion in an earlier section of this chapter on how DOE's labs can be made more hospitable to collaborative R&D.)

Since government money is involved and the purpose is to bolster U.S. competitiveness, it may make sense generally to limit membership in these joint government-private R&D projects to U.S. companies. Once again, the definition of a U.S. company would have to be settled, and conditions for foreign participation defined.[90] European experience may shed some light here, since government-industry collaboration on R&D is increasingly common in Europe. The European Community is spending over $1 billion a year on its Framework program (R&D collaborations with industry and universities). Also, 19 European countries plus the EC Commission collaborate with industry on applications-oriented R&D under the umbrella organization EUREKA. In both the Framework and EUREKA projects, foreign-owned companies can often take part provided they have an 'integrated presence"--that is, research, production, and marketing-in Europe. Not always, however. Foreign-owned companies *with* an integrated presence have been excluded from some of these R&D consortia (e.g., Ford and General Motors of Europe are excluded from PROMETHEUS, a consortium working on advanced transportation technologies). In some cases, the determining factor seems to be whether Euro-

[89]H.R. 3838, S. 1978, and S. 1191 would all require R&D entities receiving funds from the Advanced Civilian Technology Agency or the Advanced Technology Program to put in more money than the government contributes. Also, see ch. 7 for a discussion of the factors that make for success in R&D consortia, and favorable conditions forgovernment-industry collaborations. See also U.S. Congress, Office of Technology Assessment, *Commercializing High-Temperature Superconductivity*, OTA-ITE-388 (Springfield, VA: National Technical Information Service, 1988), pp. 133-37.

[90]H.R. 3838 and S, 1978 (101st Congress) provide that "no project which contains a foreign company or entity or a subsidiary thereof" shall reeligible for government financial support, unless the foreign company makes material contributions to the projects; the foreign company makes a substantial commitment to manufacture products arising from the projects's R&Din the United States and to buy from North American suppliers; the home country of the foreign company affords reciprocal treatment to U.S. companies; and the Secretary of the Department of Industry and Technology certifies (after consulting with North American participants in the project and the advisory board of the Advanced Civilian Technology Agency) that the foreign company's participation is in the interest of the United States. S. 1191 contains similar provisions.

pean members want the foreign-owned companies in or out.

Beyond Technology Policy

Technology policy, even a strategic one, carries government involvement only so far-to the brink of commercialization. After that it is up to industry. Of course, many governments, including our own, have gone farther than that in support of particular industries seen as having a special importance to the nation. Among the industrialized countries, Japan has probably gone farthest down this road. Two newly industrializing countries, Korea and Taiwan, observing Japan's success, have employed elements of the same strategy, sometimes carrying it farther.

Japan and other Asian countries have combined numerous policy tools besides long-term government support for technology R&D to promote selected industries: preferential loans from government banks or banks that follow the government's lead; guaranteed purchases by governmental bodies for home-grown products (e.g., semiconductors for Nippon Telephone & Telegraph, supercomputers for government agencies); government-subsidized leasing companies making guaranteed purchases of advanced equipment and leasing them at preferential rates (e.g., robots, CNC machine tools); formal or informal barriers against imports, removed (or partly removed) only after the domestic industry has become a world-class competitor; strict limits on foreign investment in manufacturing; government negotiations for technology licenses on behalf of industry; government guidance (not always followed) to rationalize industries, scrap overcapacity, and encourage companies to get economies of scale by specializing in certain parts of an industry (e.g., machine tools).

This is industry cum trade policy on a comprehensive scale. Other nations have used some of the constituent policies with greater or lesser success. For example, several European countries favor their national champion computer and semiconductor companies almost exclusively in government purchases. The members of the Airbus Industrie consortium get low-cost loans from their governments (France, West Germany, the United Kingdom, and Spain) and can wait to pay it back from revenues. This is an enormous advantage in an industry where it takes 10 to 14 years and at least 500 unit sales to break even on a new transport plane. The Buy American act in the United States gives a price advantage to domestic producers. U.S. Government purchases of semiconductors and computers were critical to the success of those industries in their infancies (though it cannot be said that these purchases deliberately favored domestic producers, since there were hardly any other producers at the time).

The next, and final report in OTA's assessment of Technology, Innovation, and U.S. Trade will consider trade and industrial policies of Europe, Asian nations, and the United States in depth. This report, which focuses on technology, touches only lightly on these matters, but it is relevant here to consider how strategic technology policy relates to industrial and trade policy. The justification for government's spending money on technology R&D—potentially great benefits for society, coinciding with returns to individual firms that are too small or remote to outweigh the risk-could apply, in some situations, to commercial production. This is part of the argument for protection and support of infant industries, especially ones where capital requirements are extremely high or the manufacturing technology is complex and demanding, so that it takes a long time to learn how to do it right and get costs down. Both conditions apply, for example, to civilian aircraft manufacture. According to the MIT Commission on Industrial Productivity, "no aviation company has ever succeeded without government help," though the form, degree, and timing of help has differed.[91]

This kind of thinking has led to calls for government help to get U.S. companies into the business of making consumer electronics items such as high definition TV that use advanced digital integrated circuit semiconductors and have many core technologies in common with computers (see the discussion of advanced television at the end of this chapter). One proposal is to set up a private corporation, backed by "pledges of support' from Federal, State and local governments, to provide "low-cost, very patient capital" to U.S. companies making ad-

91 MIT Commission on Industrial Productivity, "The U.S. Commercial Aircraft Industry and Its Foreign Competitors," *The Working Papers of the MIT Commission on Industrial Productivity* (Cambridge, MA: MIT Press, 1989, vol. 1, p. 16.

vanced consumer electronics products.[92] Government backing of this kind would tilt the odds in favor of investing in consumer electronics. It is one part-but a small part-of the package that adds up to industrial policy. A comprehensive public policy aimed at building up an industry for national economic security reasons would involve much more, and would probably include some aspects of trade policy, such as domestic content requirements or government negotiations on behalf of industry for foreign technologies. Opposition to such policies is based on the idea that if government actions override market signals, the result will be economic inefficiency and high prices, the extreme case being central control of the economy with shortages of everything people want, as in Poland.

A look around the world, however, shows that some governments have selectively helped industries they consider crucially important to the nation, using a full panoply of technology, financial and trade policies while still leaving the economy open to market signals. It is not an easy trick, and it is certainly not cost-free. Japanese consumers, for example, pay higher prices for some of the goods that Japanese industry excels in producing (e.g., compact cars, color television sets) than do American consumers for imports of the same products, and this difference has something to do with government policy. Yet those same Japanese consumers are worlds better off than they were 20 or 30 years ago-and this has something to with government policy too.

The last report in this assessment will take on the question of how industrial and trade policies in other nations have helped-or failed to help-their industrial advance, and which if any of these policies might be useful for the United States to try. In this report, we can say that, based on its limited use in this country and more extensive application abroad, strategic technology policy offers some attractive options for Congress to consider. This is the least intrusive and least expensive of public policies to improve the performance of industries seen as critical to the nation's economy, yet it has never yet received a broad trial in the United States. The traditional U.S. science and technology policy, which shunned government support of commercial technologies, served well enough in the postwar years when the United States was king of the mountain. Now, with U.S. manufacturing in obvious competitive difficulties, it may bean opportune time to try other approaches.

One Example of Technology Policy: The Case of Advanced Television

HDTV is an improved form of television, with a larger screen, more detail, and better color than conventional TV. If that were all it is—a bigger, more alluring form of television for home entertainment—HDTV might not have become the front page news item and center of political controversy that it was in 1989. But it is something more. Its requirements could drive a range of technologies that have important applications in other parts of the electronics industry—in particular, computers and telecommunications.[93]

There are two key reasons why technological spillovers from HDTV are likely. First HDTV's core technologies-for production, storage, transmission, processing and display of information-are in the same family as those used in computers and telecommunication devices. They are based on digital electronics. Conventional TV and many other consumer electronics items depend mainly on analog electronics technology. (Box 2-B outlines the differences between digital and analog electronics.)

In some digital electronic technologies, HDTV is ahead of computers. For example, one of HDTV's requirements is the ability to process and display huge amounts of picture data very rapidly. Because of this, HDTV must advance the state of the art in display technology (also in fast processing, although the chips and hardware being developed for this purpose for HDTV are specialized). Computers don't yet need such advanced display technology because their general-purpose hardware is slower at generating data. As computers' speed of operation increases, they will be able to take advantage of HDTV's display technology, using it in such activities as weather forecasting and computer-aided

[92] A Strategic *Industry* at Risk, a report to the President and the Congress from the National Advisory Committee on Semiconductors (Washington, DC: The Committee, 1989), p. 20.

[93] Much of the material in this section is drawn from a forthcoming OTA report, *The Big Picture: High-Definition Television and High Resolution Systems,* which provides a comprehensive account of HDTV's history, technology linkages to other electronics industries, and relation to the U.S. communications infrastructure.

Box 2-B--Digital and Analog Data: Television Transmission

In electronics, information can take two forms, digital and analog. In the digital form, numbers represent information; the numbers are generally written in the binary system, which has only two numerals, zero or one. (The familiar decimal system has ten numerals, zero through nine,) Modern digital computers represent each binary digit, or bit, as a switch; if the switch is on, the bit is one, and if off zero. In computer calculations, numbers are simply numbers, written in binary; e.g., 8 is 1000. Other data, such as letters of the alphabet, are converted to numbers according to a code, Letters usually take up eight bits; for example, the capital letter "A" is often denoted as the sequence 01000001.

In the analog form, information is represented by physical characteristics (e.g., distance or voltage) which vary continuously. Traditional sound recordings are analog. Grooves in the record have tiny physical patterns that vary continuously and correspond to the original sound. The needle of the phonograph arm rides over small bumps in the grooves, which apply pressure to a crystal (or other pickup system) in the cartridge, which in turn generates a voltage that varies with the degree of pressure applied by the needle. The electronic signal thus generated is then converted back into sound. Compact disk recordings, in contrast, are digital. Sounds are recorded on an optical disk as small pits, representing zeros or ones, which denote various characteristics-frequency, volume, and so on-according to a prearranged code. In the disk player, a solid state laser detects the pits (or their absence), and that digital signal is then converted into the corresponding sound.

When continuously varying quantities are represented in digital form, the original quantities are only approximated. For example, frequencies and volume vary continuously in music, but only certain discrete levels of frequency and volume can be represented on an optical disk. It might therefore seem that digital representation is inferior. However, the problem is handled by allowing for a great many finely spaced choices of frequency, volume, etc. The more choices allowed, the greater number of bits the system must use to represent the information. The cost of storing and manipulating great amounts of digital data continues to decline, so that a very good approximation can be quite affordable-the compact disk is one such example.

The digital form has some important advantages. Even though the initial representation in digital form is an approximation, it can be held to its original form without subsequent errors. Each copy of a digital recording reproduces exactly the sound pattern of the master, because it copies the master's pattern of ones and zeros. In traditional analog sound recording, the copying of masters introduces some distortion-which generally differs from one record to another. Distortion shows up even more in electronic transmissions. For example, when a cable television program is transmitted to a home, the signal typically passes through about 25 amplifiers along the way to keep the signal strong. Each amplifier introduces some distortion, and the distortions are compounded in the final signal received in the home. If the picture were represented in digital form, at the end of each leg the pattern of ones and zeros could be sensed and a fresh, distortion-free signal sent along the next leg of the trip. So long as the signal is good enough at the end of each leg to tell which bits have value zero and which bits have value one, the final picture can be received error free.[1]

Another advantage of the digital form is that information is easier to manipulate. For example, splicing film segments or creating special visual effects (e.g., superimposing two images) is much easier to do if the picture is stored in digital form: it is easier to rearrange data inside a machine (essentially, a special-purpose computer) than to cut or otherwise manipulate film. For another example, filtering ghost images out of television is practicable only if the picture is represented in digital form. Still another advantage is that digital data can be compressed, allowing more information to be conveyed over a given TV channel (see the discussion below). Its intrinsic advantages and sharply declining costs have made the digital form increasingly popular in recent years. Sound recording is one example. Television promises to be the next.

Conventional television uses predominantly analog information, while high definition television (HDTV) relies much more on digital information. This difference is at the heart of what is new and important about HDTV. In conventional analog TV, the picture is recorded in the studio as a series of frames (30 per second) on film or tape. Each frame shows continuous gradations in color and brightness, corresponding to the original scene. For transmission, each frame is broken down into hundreds of horizontal bands, called lines. A scanner sweeps

[1]Some early computers represented numbers in analog form and had the same problems of increasing distortion. Numbers would be represented, for example, as voltage differences. But the voltages could not be set perfectly accurately, so quantities represented inside the machine had some error. As these quantities were added, multiplied, etc., the error increased; moreover, the errors were somewhat random, so that the same calculation might yield different results. For these reasons analog computers were rejected in favor of digital computers.

continuously across each line in turn, sensing the color and brightness of each part of the picture as it goes. These continuously varying characteristics are encoded into a continuously varying electromagnetic wave (the carrier wave) which represents the visual signals through variations (modulations) in its amplitude (strength). Information can also be encoded by modulation of the wave's frequency (number of wave cycles per second), or phase (when the cycle begins); the TV sound signal is encoded by frequency changes. Any of these modulations has the effect of changing slightly the observed frequency of the carrier wave. The range over which the frequency may vary is called the bandwidth. The carrier wave, sent over the air or over cable, is picked up by a television receiver tuned to the wave's frequency band. The receiver senses the modulations in the wave, and decodes them to reconstruct the original, continuously varying, pattern of color and brightness for each line. Because of noise in transmission, the received signal has slight errors, causing some distortion in the picture displayed.

HDTV, in contrast, is a largely digital system. In some proposed systems, transmission will be entirely digital; others include an analog component for compatibility with existing receivers. While HDTV systems might be developed in ways that vary somewhat, for simplicity one example is chosen for discussion here.[2] For HDTV, the screen is divided into about 1 million or more equal rectangular or square segments, known as pixels, In any one frame, each pixel is treated as having uniform color and brightness. These characteristics are recorded in the studio as numbers on magnetic tape.[3] The color and brightness of each pixel are represented together as a sum of the three primary colors in appropriate brightnesses. For each primary color, 256 different brightnesses are possible (including the dimmest, no light at all); this requires eight bits to represent each brightness, or 24 bits to represent all three. Color and brightness do not vary continuously because only certain discrete combinations of primary colors are allowed. However, so many variations of color and brightness are available that each pixel can come very close to the original. Also, the size of the pixel limits the physical detail that can be shown, but with 1 million or more pixels, that is fine detail. These slight imperfections are less than those caused by noise in conventional TV.

Each television frame is recorded as a string of numbers that represent the color and brightness of each of the 1 million or so pixels. To record the 30 frames which comprise one second of television requires about 1 billion bits. This large amount of data must be recorded very quickly to produce HDTV programs, and it must also be manipulated quickly for transmission, reception in the home, and display on the screen,

The numerical data are encoded into an electromagnetic carrier wave, modulating its amplitude, frequency, and phase. (As with analog television, the result is to vary slightly the observed frequency of the carrier wave.) While for conventional analog television the wave's amplitude and frequency vary continuously, for HDTV they vary in only a limited number of steps, corresponding to the numerical patterns being encoded. The television receiver senses the discrete but swiftly changing variations in the incoming wave's amplitude, frequency, and phase, and then reconstructs the original pattern of bits for each frame. Based on the information for each frame, the display must be quickly updated.

For both conventional television and HDTV, the television carrier wave is allowed to vary only within a certain range of frequencies, or bandwidth; other frequency bands over the air are used for other television charnels, or for other uses such as radio and cellular telephones. Generally, the more bandwidth is available, the more information can be sent per second, As noted, the frames in 1 second of HDTV are represented by about 1 billion bits. To send that much information per second would require much more bandwidth than is available for television channels broadcast from terrestrial towers; while more bandwidth might be available by cable or satellite, even that amount would probably be insufficient. This is not surprising, since it takes much more information to transmit the finer resolution HDTV image than that to transmit the image for conventional television programs.

The solution to this shortage of bandwidth will probably involve a combination of techniques. First, the number of bits actually transmitted can be reduced or compressed, primarily by getting rid of redundant or otherwise unnecessary information, For example, if a blue sky background does not change for several seconds, it does not need to be rebroadcast in every frame. (Analog data, used in conventional TV, cannot be similarly compressed.) Also, since the eye cannot perceive fine details of fast moving objects, those objects could be sent in less detail. The calculations that do this compression before transmission, and then decompress the information on reception, are done by digital signal processor (DSP) chips, a kind of integrated circuit. HDTV will require advances in compression techniques.

[2] The selection of this example does not imply that any particular system of design specifications is Superior to any other.

[3] In some cases, a program is first recorded in analog form and later converted to digital form.

Even with compression, however, HDTV will probably also require an improvement over current technology in the amount of information that can& transmitted per second in a given bandwidth. Improved equipment will be needed to encode the bits into modulation of the carrier wave and to decode the modulation on reception. HDTV wiil also require developing DSP chips in the receiver to perform calculations to reduce or eliminate ghost images, flicker, snow, and other picture imperfections.

Actually, conventional television and HDTV are merely points on a continuum. Intermediate versions of television improved Definition Television (IDTV) and Enhanced Definition Television (EDTV), offer a finer resolution picture than conventional television, but not as fine as HDTV, For IDTV and EDTV, analog picture data is sent over the air (or over cable) but upon reception the picture is converted to digital form,

IDTV and EDTV have the advantage of being compatible with existing television systems. IDTV receivers are designed to receive current television transmissions, are being sold commercially, and are already in use in some homes. EDTV receivers require some change in the transmitted signal, but the new signal would still work with conventional receivers, HDTV transmissions that are composed of encoded compressed digital data would make no sense to conventional television receivers, which are designed to receive transmissions with analog data encoded.

IDTV and EDTV receivers perform some digital data handling similar to that needed for HDTV. For example, DSP chips reduce or remove ghost images and other flaws in the picture; also, each frame must be displayed quickly as for HDTV. However, IDTV and EDTV break the screen into fewer pixels, so that not as much data has to be manipulated each second. In sum, IDTV and EDTV are technological stepping stones to HDTV, and some of this technology is already in commercial use.

design. Other business applications, e.g., medical imaging, education, and publishing, might also use the advanced display technology developed for HDTV--indeed some early versions are already in use.

Manufacturing processes under development for HDTV might find still wider application. For example, in the long run, the most promising medium for displaying the fine-grained HDTV picture is the flat panel liquid crystal screen. The techniques needed to make these screens can be applied to methods for interconnecting chips on boards (a process that is common to almost all consumer electronics products and computers), and to other electronics products and processes as well.

This spillover to a variety of manufacturing processes in electronics brings up a second major point. To succeed in mass markets for consumer electronics products and their components, manufacturers must meet some exacting demands: high-volume production, low costs and profit margins, and high product reliability. HDTV is interesting not just because it demands new microelectronic components, but because it is a potentially large market that will also push advances in manufacturing processes, These advances come both from laboratory R&D (e.g., designing for manufacturability) and from continuous improvements on the shop-floor. Once advanced manufacturing techniques are mastered for making electronic components for HDTV, those same techniques can be applied to lower volume business products.

Cost reductions through mass production can be dramatic. For example, in the early 1970s, Plessey Ltd., a British semiconductor firm, developed a high-speed digital device able to count about 1 billion events per second. These counters, made for low-volume military and business applications, were expensive and required care to ensure proper performance. RCA, then a leader in the manufacture of television sets, saw the counters' potential application to TV tuning systems. Within about 3 years, RCA had made its own circuits, with similar performance characteristics but more robust, and was mass-producing them for about $1.50 to $3.00 apiece--one-fiftieth of their former cost.[94]

The technological importance of consumer electronics is sometimes underestimated, but the fact is that some aspects of the industry---especially manufacturing processes—are at the leading edge. Not infrequently in the past, manufacturing technology developed for consumer electronics has been applied to good effect in business products, and this kind of transfer is increasing as the consumer electronics products converge with business products in the use of digital technology (box 2-C). U.S.-owned firms

[94]John Henderson, Head, Systems Technology Research, David Sarnoff Research Center, personal communication, Jan. 5, 1990.

Box 2-C—Technology Spillovers From Consumer Electronics

Technology developments in consumer electronics have often paved the way for advances in other families of electronics products, such as computers. For example, automatic insertion of components into a printed circuit board was first developed for car radios and other consumer products, and was refined for television. That process has since been used to build computers and many other products. Another example: mass production of cathode ray tube (CRT) screens for television brought down their price enough that it was attractive to use them in personal computers.

Technological spillovers from consumer electronics to computers and other business applications are gaining importance, because the technologies are converging, For many years, business applications used mostly digital circuits, while consumer products relied more heavily on analog circuits. Recently, consumer goods have used more and more digital circuitry; and HDTV, with its huge appetite for digital circuits, some of them quite advanced in design, promises to accelerate the trend.

Already, some digital technologies that first appeared in consumer electronics are finding applications in computers. For example, the digital magnetic tape Sony developed for its 8-millimeter portable camcorder, and the digital audio tapes developed by Sony and others, are now used in computer systems to store backup data---at about one-twentieth the cost of tapes previously available.[1] Also, the digital optical disks developed for compact disk sound recordings are now used for permanent data storage for personal computers (they are known as CD-ROMs, or compact disk read-only memories in the computer world).

The spillover of technologies honed for high-volume consumer goods to other electronics sectors is uncommon in U.S. companies today. Only one major U.S.-owned company (Zenith) is still in the television business. But foreign firms-especially the Japanese-continue to use their consumer electronics technology to improve their position in computers and other business products. While Japanese firms have had other advantages as well, this transfer of technology within the firm was often a significant factor. For example, firms in Japan, Korea, and Taiwan adapted the superior CRTS they developed for television to computers, and took a 1arge share of that CRT market. Seiko and Casio exploited their liquid crystal display technology, first developed for watches, to move up to pocket computers (used for such things as computerized address books) and then to laptop computers which they sell in Japan. Canon used its expertise in optics, developed in producing consumer cameras, to help in gaining its present eminence in photocopiers. Perhaps most important, Japanese firms producing consumer products such as VCRs gained experience with automated production lines which they are now applying to the manufacture of computers.[2]

[1] Professor David Messerschmitt, Department of Electrical Engineering and Computer Science, University of California at Berkeley, personal communication, Dee, 7, 1989.

[2] These examples were given by Mark Eaton, Director, International and Associated Programs, Microelectronics & Computer Technology Corp., personal communication, Dec. 13, 1989 and Dec. 28, 1989.

have largely retreated from the consumer electronics field; this has sometimes put U.S. firms making business electronics products, such as computer CRT displays, at a disadvantage (box 2-C). HDTV, which could be one of the premier next-generation consumer electronics products, might either reverse or accelerate this trend, depending on whether U.S. firms get into HDTV production in a significant way.

At this point, some questions are in order. First, as with all new products, projections of the eventual market for HDTV are uncertain. One question is whether consumers might settle for intermediate improvements that go partway towards HDTV. These are Improved Definition Television (IDTV) and Extended Definition Television (EDTV); together with HDTV, they are known collectively as advanced television (ATV). EDTV and IDTV handle less data than HDTV; however, all the ATV *systems* rely on digital electronics (HDTV being the farthest along this path) and all require advances in manufacturing processes. In any case, both Japan and the European Community are pouring substantial government as well as private resources into making HDTV a reality. This dedication of resources into a new technology itself affects the market's growth, since it helps to drive down prices, Moreover, the Japanese Government and industry are whetting the consumers' appetites. The 1988 Seoul Olympics were broadcast in HDTV to television sets at 81 public sites in Japan; daily l-hour

HDTV broadcasts by satellite began in 1989; and NHK (the Japanese national broadcasting company) was planning to broadcast 6 or 7 hours of HDTV programs every day by 1991.

Another question is whether semiconductors, computers, telecommunications, and other electronics fields in which American firms *are* strong competitors might not do as well as HDTV in advancing technologies with important spillovers to electronics sectors other than their own. The foregoing discussion suggests that HDTV itself is not so significant a technology driver as are the underlying systems for data processing, transmission, and display, and the process technologies for manufacturing these systems. Two answers suggest themselves. First, HDTV is pretty clearly ahead in a few of the core technologies. But second, it is often impossible to be certain which application is ahead, or will remain ahead, as the driver of many of these important core technologies-and this uncertainty does not really matter. HDTV, computers, communications, and other electronics fields are all developing on separate but related tracks. So long as many of their core technologies are fundamentally similar, then advances in any or all of them are synergistic. The same research can be used to advance different industries. Each helps the others along.

This kind of synergism is less available to U.S.-owned electronics companies than to Japanese and European, because few U.S. firms are in the consumer electronics business in a major way. The Japanese Government and electronics industry are well aware of the synergisms and do their best to exploit them.[95] The same is increasingly true in the European Community.

Advanced Television as Technology Driver

Some of the core technologies being developed for HDTV, and to a lesser extent for other forms of ATV, look to be pathbreaking, and could have significant spillovers to other electronics applications.[96] Others are based on technologies that were already well developed for other uses; further development for ATV probably will not create major breakthroughs, but might offer incremental improvements useful elsewhere. Still others that are needed for ATV may be developed first for other uses. While some of the following examples of technologies in which ATV seems to have the lead may turn out to be mistaken, others, in hindsight, probably could be found to take their place.

Flat Panel Liquid Crystal Displays-Display is high on the list of technologies likely to driven by HDTV—indeed by all forms of ATV. Not only will the displays themselves be adaptable to other uses, the manufacturing processes for making them could also be widely applied.

Looking ahead to the year 2000, the best candidate for displaying the HDTV picture (and probably any ATV picture) appears to be flat panel liquid crystal displays. This form of display has the advantages of low power consumption, good color range, and compact size.[97] The display contains a glass screen with elements made of a liquid crystal, which change the way they pass or reflect light when they are subjected to a small polarizing voltage. Electrical circuits are put right on the glass to control each of the liquid crystal elements to produce the desired picture.

Liquid crystal displays have long been in use, e.g., in digital watches. The challenge is to make them in the large size and with the fast response and great detail (millions of display elements) needed for HDTV--all at a cost that consumers can afford. Making liquid crystal displays for HDTV will push some areas of manufacturing technology that have wide application in other electronics sectors. (The same is true of IDTV and EDTV, although to a slightly lesser degree, because they require fewer pixels for display than HDTV and the screen might

95 Gregory Tassey, "Structural Change and Competitiveness: The U.S. Semiconductor Industry, *Technological Forecasting and Social Change*, vol. 38, 1990 (forthcoming); Barry Whalen, Senior Vice President for Plans and Programs, and Mark Eaton, Director, International and Associated Programs, Microelectronics & Computer Technology Corp., letter to John Glenn, Chairman, Senate Committee on Governmental Affairs, July 31, 1989, reprinted in *Prospects for Development of a* U.S. *HDTV* Industry, hearings before the Senate Committee on Governmental Affairs, Aug. 1, 1989, [S, Hrg.] 101-226, pp. 522, 524-25 (letter discusses Japan's Giant Electronics project, and includes translation of two pages of project's plan); Lansing Felker, Director, Industrial Technology Partnership Program, U.S. Department of Commerce, personal communication, Nov. 21, 1989.

96 For a more detailed discussion of linkages between HDTV and other electronics industries, see OTA's forthcoming report, *The* Big *Picture*, op. cit., ch. 5.

97 The CRT displays currently used for television consume much more power. They are also bulky-nearly as deep as the screen is wide, in today's models-and breakable. Unless greatly slimmed down, with the large screen required to show off HDTV to advantage (40-inch diagonal or more), they would weigh several hundred pounds and would scarcely fit in the door of most houses.

be somewhat smaller. See box 2-B for a definition of pixels.)

Some of the advances in manufacturing required for making liquid crystal displays for ATV are: the ability to make extremely flat glass panels of large size (the area of the display screen); precise etching of electric circuit patterns over the entire screen area; deposition of thin films of material over this area with uniform thickness; and new techniques for attaching electrical leads and testing finished circuits. Japan's Ministry of International Trade and Industry expects that Japanese R&D for flat panel liquid crystal displays, all told, will have applications in a great many areas. Some examples are ultra-high density optical recording systems, ultra-thin photocopying systems, solar cells, optical engraving, large flat light sources, high-precision electronic components, and a better method for interconnecting semiconductor chips.

This last application is particularly significant. The requirement for interconnection of integrated circuits (chips) is ubiquitous in consumer electronics and computer applications. The traditional practice is to put each chip in a plastic or ceramic package with metal electrical leads, then mount the packages on a printed circuit board (a pattern of circuits consisting of copper foil laminated to sheets of fiberglass reinforced epoxy), and then connect the chip's leads to the board's circuits. The method is expensive and somewhat unreliable (connections occasionally come loose), and it limits how densely circuits can be packed. The less dense the packing, the longer the path the electrical signals must take; longer paths slow down computations, and thus limit the speed of computers based on this technology for interconnections.

The emerging 'chip on glass" technology allows greater density and reliability. In this system, the bare, unpackaged chips are mounted directly onto glass (or another insulating substrate), and the chips' own tiny leads are connected to a fine pattern of circuits etched on the glass. The technology demands high precision over a large area both in etching the circuits and in film deposition. Large area lithography-a technique to do these steps at low cost for mass production of chips on glass-will probably be developed frost (at least in part) for manufacturing HDTV displays.

Another requirement for the chip on glass technology is a method of connecting the chip's minute leads to the precision etched circuit on the glass. One such technique is tape automated bonding (TAB), in which adhesive tape with electrical leads connects the chips to the circuit board-and in television with a liquid crystal display, to the display as well. Japanese firms are already using TAB to make miniature televisions with liquid crystal displays; in fact, the Sony Watchman miniature television uses more demanding TAB than the NEC SX-2 supercomputer.[98] In developing HDTV, Japanese firms are pushing TAB technology still further. U.S. electronics firms have lagged behind in TAB technology, even though it was invented in the United States.

As manufacturing of liquid crystal displays for ATV improves, the displays will become cheaper and more reliable, and will probably find many applications in business products-specially computers. Liquid crystal displays for ATV and for computers are essentially similar, although ATV displays require more choices of color and brightness and computer displays require more closely spaced pixels. Lap-top personal computers already use flat panel displays. More powerful computers will probably follow.

Digital Signal Processor Chips and Computer Simulation--The amount of information in a real-time, high-definition, full color HDTV signal is huge—as much as 1.2 billion bits per second in some systems. HDTV is driving state-of-the-art technology in processing so much information at high speed. The chips that process the information flows for HDTV are tailored to its specific needs but might be adapted to other signal processing applications, such as compressing speech for transmission. More generally, some of the technologies needed to handle HDTV's complex, high-speed chips could have important spillovers--e.g., high-performance circuit boards made of new, cheaper materials. Another spillover could come from the methods used to design chips for HDTV.

HDTV picture data are so voluminous that they demand more bandwidth than is available in most

[98] National Research Council, Commission on Engineering and Technical Systems, Manufacturing Studies Board, *The Future of Electronics Assembly: Report of the Panel on Strategic Electronics Manufacturing Technologies* (Washington, DC: National Academy Press, 1988), p. 55.

transmission systems (certainly in broadcasts from terrestrial towers), and therefore have to be compressed before transmission. This compression of data, and decompression upon reception, are done by specialized integrated circuits, digital signal processor (DSP) chips. DSP chips are also used in all ATV to reduce or eliminate ghost images, flicker, snow, and other picture imperfections. The design of the complex calculations to be performed by those chips is made much faster and cheaper by computer simulation. Operations the chip would perform with hardware are first tried out by software on the computer, since the computer can readily be reprogrammed to experiment with different designs before a real chip is ever made.

Because the DSP chips for HDTV must perform calculations with many billions of steps per second, computer simulations of their operation are difficult. Normally, computers running simulation programs perform much more slowly than the hardware being simulated. It is a major challenge to get computers to simulate DSP calculations fast enough to generate video images at the normal viewing speed. (Viewing at normal speed is necessary to assess the picture quality.)

A working prototype computer to perform such simulations has been built by the David Sarnoff Research Center in the United States, under contract to Thomson Consumer Electronics, a U.S. subsidiary of the French firm (partly owned by the French Government) Thomson SA.[99] In late 1989, Thomson began to use this machine as a design testbed to develop IDTV receivers; Thomson expects to use it to help develop DSP chips for all future advanced television systems.[100] Japanese firms have been developing similar testbed computers.

To achieve simulation at actual viewing speeds, the firms involved have chosen a parallel processing approach, in which many processors (essentially, many individual computers) all work on the problem at the same time. Parallel processing-especially when it uses many hundreds of processors—is a cutting-edge area of computer technology, useful for solving a great many problems from aircraft design to weather forecasting. Massively parallel machines will take an increasing share of the supercomputer market because they provide great computing power at relatively low cost. The firms that use parallel processing computer testbeds to design DSP calculations are gaining experience in hardware and software for parallel processing generally. This helps Japanese firms' efforts to catch up to U.S. firms in parallel processing.

Digital Filters--The digital filter, a kind of DSP chip, has many uses in electronics products, including selecting frequencies and reducing noise. 'In TV reception, for example, the home set may receive not only the direct television signal but also a weaker, delayed version of the signal reflected off a building. This causes a ghost image, which digital filters can reduce or remove when the picture is represented inside the TV receiver in digital form. Digital filters are also used in other systems--e. g., in telephone networks, to reduce noise from reflections within the system; in military radios, to select frequencies and reduce noise; and in compact disk players, to select frequencies. Despite much past R&D, digital filters are still hard to design. As part of its HDTV development work, Thomson Consumer Electronics has engaged the David Sarnoff Research Center for work on making the design easier. This research will permit easier design of digital filters for other applications as well.[101]

Digital Modulation Techniques—HDTV will require new transmission and reception systems, to allow the transmission of more information in a given bandwidth than is needed for conventional color television today. Among other things, these systems will use new, more efficient ways of encoding digital data into variations in the amplitude, frequency, and phase of an electromagnetic wave. This encoding is called modulation. Once more efficient modulation techniques are developed for HDTV, they might be used generally to enhance the information-carrying capacity of other digital

[99] Thomson Consumer Electronics consists of the old RCA consumer products group, which General Electric bought and then sold to Thomson SA.

[100] Dr. D. Joseph Donahue, Senior Vice President, Technology and Business Development, Thomson Consumer Electronics, personal communication, Jan. 2, 1990; see also Danny Chin, Joseph Passe, et al., The Princeton Engine: A Real-Time Video System Simulator,' *IEEE Transactions on Consumer Electronics,* vol. *34, No. 2, 1988,* p, 285.

[101] John Henderson, Head, Systems Technology Research, David Sarnoff Research Center, personal communication, Dec. 7, 1989. While digital faltering can be done by software, that would be too slow for television applications. 'he digital filters used for television are hardware devices. They are adaptive filters, meaning that they can adjust their operation to a changing delay between the original signal and its reflection. The filter senses the delay using a special calibrating signal transmitted at regular intervals.

communications systems, such as microwave phone links and digital satellite transmissions.

Fiber Optic Communications--HDTV might provide the first demand for fiber optic communications to the home. If a large proportion of U.S. homes are connected to a fiber optic network, the network's electronic components residing in the homes would be manufactured in very large quantities, and would justify R&D to reduce manufacturing costs. The electronics needed to connect each home have a great deal in common with electronics needed elsewhere in the network. For example, requirements for wiring up the home would include: 1) electronic components for receiving and amplifying light signals;[102] 2) digital signal processing adapted to the available bandwidth (greater than that available for over-the-air broadcasts); and 3) fiber optic cable which is easy for a service technician to install and repair. All of these features are also needed at other points in fiber optic networks.[103] Companies that cut costs for mass wiring of homes would realize cost advantages generally in building a fiber optic network. They would have the advantage in providing other fiber optic services, such as data transfer between computers.

Government Policy and ATV

Although the technological spillovers among different branches of the electronics industry cannot be pinned down or forecast with precision, the examples given above suggest the breadth of the synergism between the advancing, increasingly digitalized consumer electronics branch-with HDTV in the lead—and the computer and telecommunications branches. Because of these interactions, some of the technologies that have to be developed for advanced television systems look like strong candidates for government support. There are strong candidates as well in fields other than advanced television. As of now, however, no agency of the U.S. Government has the mandate to select from among these possibilities, or the money to give strong R&D support to civilian technologies that have the potential for large, long-term benefits to society, but are too risky to attract adequate private investment.

The U.S. microelectronics industry is at a double disadvantage in creating and exploiting advanced technologies that are common to consumer and other electronics sectors. First, the consumer electronics industry in this country is limited. In television, only one major company (Zenith) is U.S.-owned; all the rest are foreign-owned. This is not an insuperable barrier to development of new technologies important to ATV within the United States—witness the fact that Thomson Consumer Electronics (French-owned) engaged the Sarnoff lab (American-owned and staffed) to build a computer that could help design DSP chips for ATV. It is a handicap, however, that most U.S. electronics companies are not in the TV business. Second, government is playing a critical role in developing HDTV technologies in both Japan and Europe.[104] This kind of help is almost entirely lacking in the United States.

The Japanese Government has worked with industry for over 25 years on developing HDTV and its components, putting HDTV in the wider context of technology development for a knowledge-intensive economy. NHK, Japan's quasi-public national television and radio broadcast company, has invested about $150 million in R&D related to HDTV since the mid- 1960s, financing its contributions from household TV subscription fees. NHK also organized and parceled out some of the R&D done by private companies. (Private investment over the years is estimated at $700 million to $1.3 billion.) MITI and the Ministry of Posts & Telecommunications (MPT) added support for R&D,[105] while the government's low-cost loan programs have encouraged private investment in production facilities. NHK and private companies have also concentrated on developing programs for HDTV, and the government-supported space program launches the satellites for broadcasting.

European countries got a later start but, according to those close to the scene, were only a couple of years behind the Japanese by 1990. First, at a meeting on international telecommunications stand-

[102] If services requiring two-way communication, such as tele-shopping, are provided, Components to transmit optical signals would also be needed.

[103] These examples were given by Jules Bellisio, Manager, Video Systems Technology Research Division, Bellcore, personal communication, Jan. 2, 1990.

[104] For a more detailed discussion of foreign governments' support of HDTV development, see OTA, *The Big Picture*, op. cit., ch. 2.

[105] MITI, for example, organized and partially supports the Giant Electronics Project, a 7-year effort to develop core technologies relevant to a40-inch flat panel display and many other applications by 1996.

ards in May 1986, the European countries refused to accept the Japanese HDTV production standard, on grounds that it was incompatible with European systems, but also because of the threat to European TV manufacturers. A month later, the Europeans formed the joint venture EUREKA Project 95 to develop their own version of HDTV; the consortium now includes two dozen organizations from nine European countries. When the first phase of the project ended in December 1989, the members had spent $318 million, of which 40 percent was contributed by governments and the rest by private companies, and the consortium was ready to begin satellite transmission tests. It expects to make full-scale HDTV broadcasts by 1994. Meanwhile, the European Community has adopted local origin requirements for electronics, in which EC goods are defined as those where the "most substantial transformation' took place in Europe. Non-EC goods are subject to tariffs, quotas, discrimination in public procurement and, when dumping is claimed, anti-dumping actions (which the EC is vigorously pursuing).

The U.S. Government, by contrast, has been very little involved with HDTV. Indeed, the U.S. State Department originally supported the Japanese standard for producing HDTV program material; not until May 1989 was this position reversed. The one positive government action to support HDTV technology came from the Department of Defense. In December 1988, the Defense Advanced Research Projects Agency (DARPA) invited industry participation in a 3-year $30 million program of R&D for high-resolution displays and supporting electronics. Within a few months, 87 companies applied to collaborate with DARPA, in proposals totaling $200 million. By the end of 1989, DARPA had selected five contractors, with more to come.

Despite its technical savvy and fine record, DARPA is not the ideal agency to support technologies of great importance to the civilian economy. Its central mission, after all, is to fund long-range R&D that supports military security. Although it has sometimes interpreted that mission broadly enough to encompass technologies on the commercial side, since they have military as well as civilian uses, it has also, on occasion, had to narrow its focus and put strictly military needs frost. A civilian technology agency could be given the job of weighing the claims of various commercial technologies in a systematic and proactive way. Guided by industry's counsel and industry's willingness to put up its own money, the agency would have to consider what technologies are likely to fortify the long-range economic as well as military security of the Nation, whether government R&D support is needed, and if so, where it would count most.

Government support for R&D is clearly no guarantee of success in developing new commercial technologies-especially when it comes to a consumer product like advanced television. Recall that some of the most important linkages between consumer electronics, on the one hand, and such things as computers and telecommunications, on the other, are in the manufacturing process. Both the condition and dividend of success in the demanding mass consumer electronics market is excellence in manufacturing. And excellence in manufacturing comes from interaction between the R&D that generates better equipment and processes, and practice on the shop floor. Thus, government R&D support for the core technologies of importance to several electronic sectors is only one ingredient in the synergism that nurtures all of them.

Chapter 3

Financing Long-Term Investments

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Chapter 3
Financing Long-Term Investments

Developing improved technology requires long-term investment. This is true of all the activities involved in technological advance-research, development, commercialization, and acquisition of new capital equipment. All these undertakings have a better chance of success when there is a steady commitment of money, often for several years before the investment begins to pay off.

Much has been said about the short planning horizons of American business managers compared with the longer term view taken by foreign competitors, especially the Japanese. Because Japan's economic success shows most clearly what long-term investment can accomplish, this section concentrates mostly on Japan, although examples from other countries (e.g., Germany and South Korea) would be equally appropriate.

Several explanations have been offered for the Japanese propensity to take the long-term view, and for the American focus on shorter term returns. One is, simply, national culture and, by extension, business culture. But this is less an explanation than an observation. A factor with more explanatory power is the remarkable growth of the Japanese economy since World War II, and the comparatively sluggish growth, on average, of the post-1960s American economy. American firms, doing most of their business domestically, faced potential growth rates whose mean was close to overall economic growth-3 percent per year or so, in real terms. Japanese manufacturers, however, were also looking outward, and had not only their own rapidly growing market to expand into, but the U.S. market as well. When markets are expanding at a rapid clip, investment for greater market share over the long term can reap more rewards than playing for short-term gains. Conversely, economic stagnation, recession, or even sluggish growth can work to the detriment of long-term investors and make winners out of short-term profit takers.

Japan's rapid economic growth in the postwar period and its government's effectiveness in promoting swift recovery from the oil shocks and recessions of the 1970s and 1980s partially explain the penchant of Japanese managers to focus on the long term. Likewise, sluggish growth explains some, but not all, of America's managerial myopia. Another determining factor is the financial environment. If a focus on short-term returns and profits is hurting American firms in competition with Japanese and German fins-and this is widely accepted as true-then it follows either that U.S. managers persist in ill-judged strategies in the face of evidence to the contrary, or that there is something about such strategies that is rational, viewed from the perspective of the managers. To achieve any long-lasting changes in the strategic behavior of American fins, it is necessary to understand how the American financial environment fosters short-term strategies, and how the Japanese financial environment resists such pressures.

A major part of the answer lies in the terms on which capital is provided, which includes, but is not limited to, its cost. By common consent, Japanese firms have deep pockets and patient capital. Patient capital is, almost by definition, low-cost capital, or it behaves like low-cost capital. And there is substantial evidence that Japanese businesses have enjoyed lower cost capital than American firms over most of the postwar period. Moreover, the financial climate has encouraged relatively heavy investment in things like R&D and fixed capital to an even greater extent than differences in simple cost of capital suggest. The question is why.

Today, when Japanese national income per capita is among the world's highest and Japanese corporations are swimming in profits, it may be hard to remember that, not so long ago, capital was relatively scarce in Japan. The Japanese personal savings rate has been extraordinarily high throughout the postwar period. But initially, incomes were low, so the total amount saved was not very great. On the other side of the ledger, demands for capital were high, mainly to feed the appetite for investment capital of a rapidly industrializing economy but also to finance frequent deficits in the national government budget. The workings of free capital markets do not explain the low cost of capital to Japanese firms during those years. The wide gap between American and Japanese capital costs, through the mid-1970s at least, was a result of government regulation of the Japanese financial market.

Today, after years of deregulation, Japanese financial markets have become more open, and real

interest rates, many suggest, have converged somewhat with American ones. Yet even if interest rates were the same, the risks to business in making long-term investments might still be lower in Japan. That is, in large part, because both debt and equity financing are provided on a less risky, more long-term basis in Japan (and Germany) than in the United States, in effect lowering the cost of capital to Japanese firms even if the cost of funds (interest rate paid on debt capital, for example) were the same as America's.

INTERNATIONAL CAPITAL COSTS

An often-repeated argument holds that if money flows freely between nations there should be no difference in the cost of capital based on the national identity of fins. Investment capital, regardless of its origin, will seek investments that are expected to yield the highest return, and investors will seek the best terms from creditors. If there are enough of both (that is, if no investor or creditor has inordinate market power), capital flows should be sensitive only to risk. This argument presumes, logically, that there is no difference in risk based on nationality. And indeed, one study concludes that there is no persistent difference in real short-term interest rates between the United States and Japan (the nation most often alleged to enjoy favorable terms on capital provision).[1]

There are many flaws in this kind of argument. Short-term interest rates are not a very relevant basis for comparison, and comparisons of other real rates do show a difference between Japan and the United States. For instance, the real lending rate in the United States in the 1980s was higher than that of Japan by 1.1 to 4.8 percentage points, averaging 2.6 percentage points.[2] But a more fundamental flaw is the failure to take into account the difference between cost of funds—interest rates or the cost of equity-and the cost of capital, which is influenced by corporate tax rates, the economic depreciation of the investment and its tax treatment, and other fiscal incentives for investment.[3] Numerous studies have documented the gap-sometimes several percentage points—between Japanese and American capital costs over the past two or more decades.[4] Jorgenson and Kuroda, for example, estimate that Japan's lower capital costs have been a very important contributor to the increasing international competitiveness of Japanese firms over the postwar period, excepting the years 1973, 1978, and 1989 (figure 3-1).5

The most thorough study, comparing capital costs of the United States, Japan, West Germany, and the United Kingdom, calculated capital costs for various types of investment, including research and development, new plants, and machinery and equipment. The study concluded that American and British capital costs for all types of investment were substantially higher than those of Japan and West Germany over the period 1977 to 1988 (figures 3-2 to 3-4). Specifically, each year from 1977 to 1988, the cost of capital in America averaged 3.4 percentage points higher than the cost of capital in Japan for investments in machinery and equipment with a physical life of 20 years; 4.9 percentage points higher for a factory with a physical life of 40 years; and 8 percentage points higher for a research and development project with a 10-year payoff lag.[6]

The impact of differences this great is profound. Even small disparities can be important and have long-lasting effects. A 1-percentage-point difference

[1] National Science Foundation, *The Semiconductor Industry*, Report of a Federal Interagency Staff Working Group (Washington, DC: Nov. 16, 1987), p. 36. This point is quite debatable, even on short-term rates. The NSF study does not mention which short-term rates were compared, and other studies have concluded that there are substantial differences in short-term interest rates.

[2] The prime lending rate in the United States, and the lending rate in Japan, according to *International Financial Statistics*. The rates were deflated using GDP deflators, from the Organization for Economic Cooperation and Development.

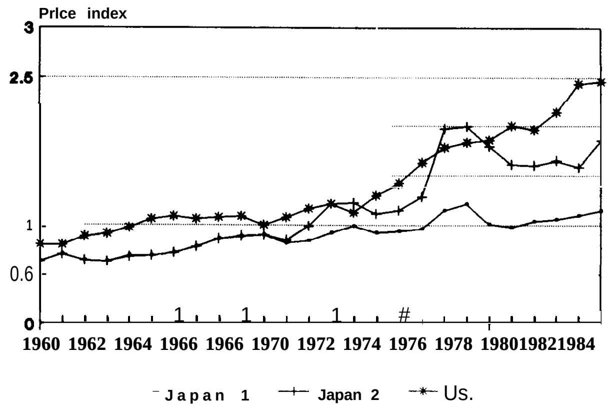
[3] Robert N. McCauley and Steven A Zimmer, "Explaining International Differences in the Cost of Capital,' *Federal Reserve Bank of New York Quarterly Review*, summer 1989, pp. 7-28.

[4] For example, see ''U.S. and Japanese Semiconductor Industries: A Financial Comparison, ' Chase Financial Policy for the Semiconductor Industry Association, June 9, 1980; George N. Hatsopoulos and Stephen H. Brooks, 'The Gap in the Cost of Capital: Causes, Effects, and Remedies,' *Technology and Economic Policy*, Ralph Landau and Dale Jorgenson (eds.) (Cambridge, MA: Ballinger Publishing Co., 1986); Albert Ando and Alan J, Auerbach, ''The Cost of Capital in the U.S. and Japan: A Comparison,' Working Paper No. 2286, National Bureau of Economic Research, Inc., June 1987; and Dale W. Jorgenson and Masahiro Kuroda, ' 'Productivity and International Competitiveness in Japan and the United States, 1960- 1985,' paper presented at the Social Science Research Council Conference on International Productivity and Competitiveness, Stanford, CA, Oct. 28-30, 1988.

[5] Dale W. Jorgenson and Masahiro Kuroda, "Productivity and International Competitiveness in Japan and the United States, 1960-1985," paper presented at the Social Science Research Council Conference on International Productivity and Competitiveness, Stanford, CA, Oct. 28-30, 1988.

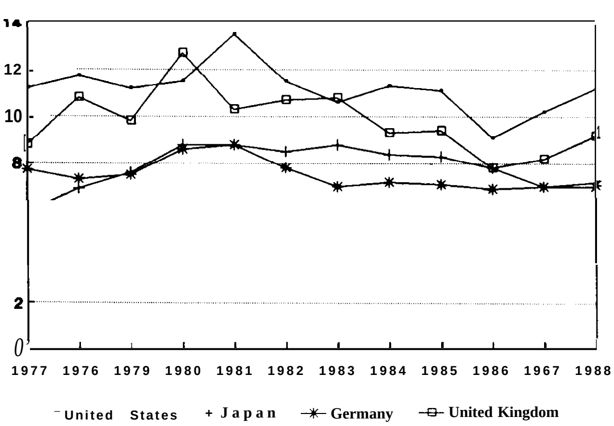
[6] McCauley and Zimmer, op. cit., p. 16.

Figure 3-1--Capital Input Prices, United States and Japan



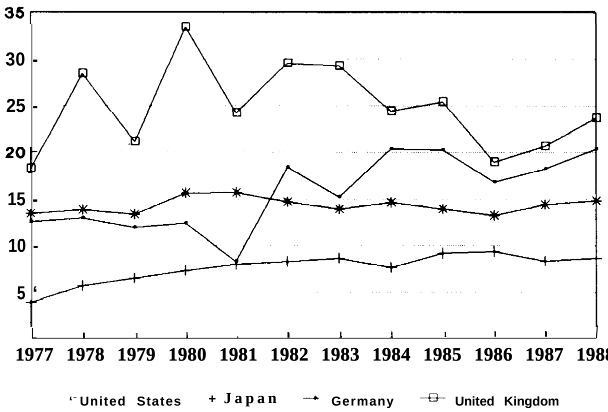
SOURCE: Dale W. Jorgenson and Masahiro Kuroda, "Productivity and International Competitiveness in Japan and the United States, 1960 -85," paper presented at the Social Science Research Council Conference on International Productivity, Stanford, CA, Oct. 28-30, 1988.

Figure 3-2-Comparative Capital Costs: Equipment and Machinery, 20-Year Life



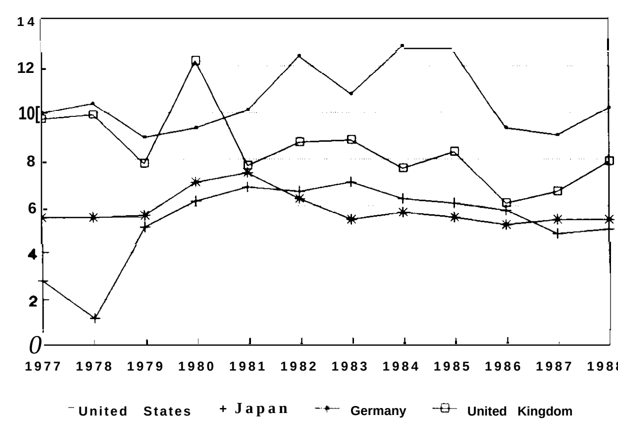
SOURCE: Robert N. McCauley and Steven A. Zimmer, "Explaining International Differences in the Cost of Capital," *Federal Reserve Bank of New York Quarterly Review,* summer 1989, table 2.

Figure 3-3-Comparative Capital Costs: R&D, 10-Year Payoff



SOURCE: Robert N. McCauley and Steven A. Zimmer, "Explaining International Differences in the Cost of Capital," *Federal Reserve Bank of New York Quarterly Review,* summer 1989, table 2.

Figure 3-4-Comparative Capital Costs: Factory, 40-Year Life



SOURCE: Robert N. McCauley and Steven A. Zimmer, "Explaining International Differences in the Cost of Capital," *Federal Reserve Bank of New York Quarterly Review,* summer 1989, table 2.

in the after-tax cost of capital can result in differences in capital stock of 7 to 13 percent in the long run.[7] Even if American and Japanese capital costs were the same today—which they are not—markedly lower costs in previous decades in Japan would still favor the Japanese firms.

Sustained differences in capital costs of the magnitudes shown by McCauley and Zimmer are not likely under free market conditions in international finance.[8] Based on evidence of capital-cost differences alone, we would conclude that the financial market of either the United States or Japan

[7] M. Fukao and M. Hanazaki, "Internationalization of Financial Markets: Some Implications for Macroeconomic Policy and fOr the Allocation of Capital," OECD Working Paper, No. 3, November 1986.

[8] It is quite possible, however, that smaller differences could be sustained simply by different calculations of investment risk based on currency fluctuations, even if capital moves across national borders without restriction. A Japanese investor, for example, might insist on a higher return on a foreign investment than on a comparable domestic one simply to cover the risk of losses induced solely by changes in currency value.

is not free to seek its own equilibrium. Since the American financial market is known to be relatively open internationally, and interest rates are higher here, the hypothesis is that the Japanese financial market has been controlled. That is in fact the case.

Moreover, regulated financial markets are not the only influence on capital investment or formation. Tax incentives and exemptions are widely used to promote capital investment in Japan, often for quite specific purposes. The Japanese main-bank system has also played a crucial part in lowering capital costs and reducing the risk of investment in Japan.[9] So, too, has the Japanese network of stable shareholding, designed to help managers resist pressure from equity owners to concentrate on short-term profits and dividends at the expense of market share.

The American financial environment is markedly dissimilar. Not only are there fewer provisions, public and private, to promote investment, but the government gives less effort to maintaining overall macroeconomic stability, shareholders demand much greater accountability, and relationships between banks and companies they lend to are more distant. Moreover, the pressure exerted by the financial environment to focus on short-term payoff, or simply to invest less compared with Japan, is growing.

The Japanese Financial Market: Sharing the Risk

Capital costs are based on risk. Riskier investments must promise higher returns to induce investors to provide capital. There is evidence based on the likely future earnings potential of American and Japanese firms in 1989 that the international Japanese manufacturing firms could now be better bets than the American ones. While they were often satisfied with lower profits in the past, many international Japanese firms are earning handsome profits now; their reputations are sounder, and their capital spending plans are lavish. A 26.3 percent real increase is anticipated in Japanese capital spending in manufacturing in fiscal year 1989, and 11.8 percent overall,[10] compared with a 12.1 percent increase planned expenditures on new plant and equipment on the part of U.S. manufacturers.[11] A stable prosperous future for Japanese manufacturers is a recent development, at least in the eyes of international investors. In the 1960s and even in the 1970s, large, long-term investments by Japanese companies in markets dominated by European and American corporate giants must have been viewed with much more skepticism than comparable large investments in Japan now. Yet this higher degree of risk was not perceived in the same way in Japan, nor was it reflected in the costs of capital for large Japanese manufacturing concerns.

The regulation of many facets of the financial system of Japan made it possible for these companies to get low-cost capital. According to Abegglen and Stalk, "[t]he policy of the Japanese government is, and long has been, to hold interest rates to industry at as low a level as prudent monetary policy management allows. ' '[12] Until the 1980s, Japan's financial market was effectively closed to outsiders, and Japanese investors had few options for investment outside Japan.[13] Moreover, Japan's financial system spread the risks of long-term investments in industrial development widely among banks, savers, consumers, and corporations. This was done through controlled interest rates; tax policies that limited consumer spending, encouraged saving and transferred household savings to businesses on very favorable terms; and a variety of tax incentives that reduced the cost of investment. In America, much more of the risk of long-term investment is borne by

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9Y. Kurosawa, op. cit.

10The Japan Development Bank, ''The Japan Development Bank Reports on Capital Spending: Survey for Fiscal Year 1988 -90,' mimeo, September 1989, pp. 2-3. Mr. Nobuyuki Arai, Deputy Manager and Economist of the Economic and Industrial Research Department of JDB expects these planned targets to be met. Personal communication with Mr. Arai, November 1988.

11U.S. Department of Commerce, Bureau of Economic Analysis, "Plant and Equipment Expenditures, the Four Quarters of 1988, ' Survey *of Current Business*, September 1988, p. 19.

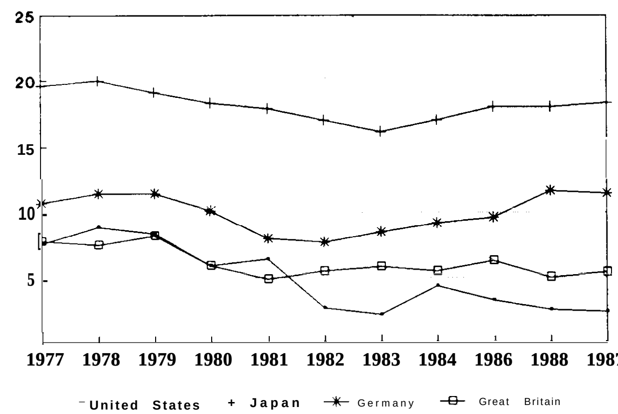
12James C. A@@ and George Stalk, Jr., *Kaisha, the Japanese Corporation* (New York, NY: Basic Books, Inc., 1985), p. 178.

13The following discussion draws heavily from the following sources: M. Therese Flaherty and Hiroyuki Itami, ' 'Finance,' *Competitive Edge: The Semiconductor Industry* in *the U.S. and Japan,* Okimoto, Sugano and Weinstein (eds.) (Stanford, CA: Stanford University Press, 1984), pp. 135-76. Philip A. Wellons, "competitiveness in the World Economy: The Role of the U.S. Financial System," *U.S. Competitiveness in the World Economy,* Bruce R. Scott and George C, Lodge (eds.) (Boston, MA: Harvard Business School Press, 1985), pp. 357-394.

the corporation itself.[14] In addition, Japan's high rate of savings and rapidly rising income levels have provided an increasingly generous pool of capital for investment. Since World War II, net savings as a percent of GNP averaged well above 20 percent in Japan through the late 1970s, and have declined only modestly since. Net savings as a percent of GNP have rarely approached as much as 15 percent in other advanced industrial democracies.[15] America is the worst performer among the most advanced OECD nations; net saving hovered at just below 10 percent of GNP through the end of the 1970s, and then plummeted, reaching a low of 2.4 percent in 1987, and then recovered slightly (figure 3-5). Capital formation, as a percent of GDP, has also been higher in Japan than in the United States or OECD Europe (figure 3-6). Finally, Japanese lenders—stockholders and large city banks-tend to have much closer and more influential relationships with their corporate debtors than is the case in the United States.[16]

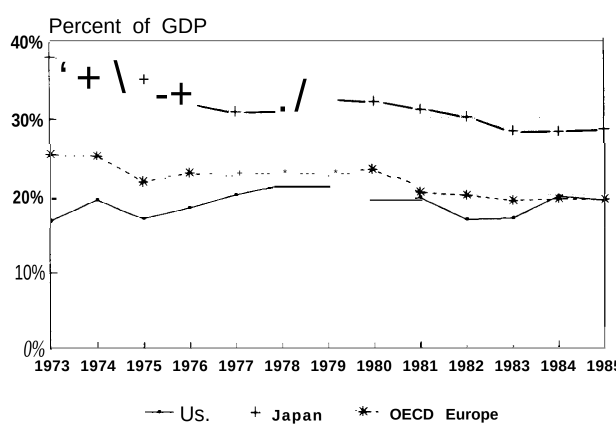
Although some of the conditions described above are slowly changing as the Japanese financial system is deregulated, their combined influence over the postwar period was to give Japanese firms substantially more freedom to make riskier, long-term investments at lower cost than American (or probably European) firms enjoyed. From this perspective, Japan's much-touted long-term vision—and correspondingly, the much remarked myopia of American managers—becomes understandable. Rational managers, operating under the rules and conditions of financing in both countries, could be expected to behave quite differently. This view is persuasive even if the numerical difference in interest rates—as low as 1 to 3 percentage points, according to some analyses--is modest.

Figure 3-5-Net Savings, Percentage of Gross Domestic Product



SOURCE: Organization for Economic Cooperation and Development, *Historical* Statistics 1960-87 (Paris, France: 1989), table 6.16.

Figure 3-6--Capital Formation in the United States, Japan, and OECD Europe



SOURCE: Organization for Economic Cooperation and Development, *National Accounts* 1960-1964 (Paris, France: 1986).

The sharing of risk in Japan is not the result of any single action or actor, but rather of a variety of institutions and laws. Moreover, the risk-sharing that lowers the cost of capital to corporations does not apply to consumers. The factors that spread the risk of business investment include closed or controlled financial markets, channeling of funds to businesses and away from consumer loans, a large pool of savings for investment, and close relationships between companies and capital providers (banks, affiliated financial institutions, government institutions, and stockholders). For targeted industries-those viewed as having most promise for development —there are other mechanisms as well,

[14]The developed economies of Western Europe, except West Germany, more closely approximate the American model than the Japanese, at least in terms of capital costs, according to available evidence. See, for example, Y. Suzuki, *Money and Banking in Contemporary Japan (New* Haven, CT: Yale University Press, 1980).

[15]Flaherty and Itami, op. cit., p. 137.

[16]For example, Corbett makes the Point that Japanese banks probably monitor the companies they lend heavily to more actively than is the case in other countries. See Jemy Corbett, "International Perspectives on Financing: Evidence from Japan," *Oxford Review of Economic Policy, vol. 3, No. 4, 1987, p. 45.*

some of them explicit (subsidies for R&D and capital investment, for example) and some implicit or consensual, such as protection from the threat of hostile takeovers.[17]

Controlled Financial Markets—The history of the Japanese financial system is a study in control and fragmentation. Although recent market-opening moves have gained widespread attention. it is only in the 1980s, under intense internal and external pressure, that real liberalization has occurred, and even so, Japan's financial market remains one of the world's more controlled.[18] Between World War II and the early 1980s, a dominant purpose of the Japanese financial system was to revive and strengthen Japanese industry, often at the expense of consumers. Guidance of the financial system had two aims, subsumed under the single purpose of promoting Japan's reconstruction and economic development. First, the system was designed to favor business investment instead of current consumption, or, in the words of an official of the Ministry of Finance, ''to prepare the ground for industry to walk on."[19] Second, the government selectively promoted heavier investment in certain sectors as a part of Japan's industrial policy, and also helped non-targeted industries cope with the costs of adjustment.

Preparing the Ground-Japan was a poor country after World War II. Its needs for capital were enormous. Much of its industry had been devastated by or dismantled after the war, and the *zaibatsu,* family-controlled bank-holding companies that were major providers of capital pre-war, were dismantled during the occupation.[20] To rebuild industrial production--and then, beginning in the 1950s and 1960s, to accelerate development of targeted industries like machinery, motor vehicles, and electronics--required what capital there was in Japan to be preferentially provided to utilities and manufacturing. Several things made this transfusion possible.

Japan's financial institutions were compartmentalized and fragmented, each with its own rather narrow purpose and with many proscriptions on its behavior. Briefly, the institutions worked together to increase savings rates (generating capital for investment) and pass them on to industrial users without high costs. They also worked to reduce the risk associated with financial downturns and the costs of financial distress to the firms.[21] The institutions that promoted high savings rates in Japan included a lump-sum payment at retirement (rather than a lifetime annuity) and a marginal system of social security (though this is changing to become more generous); large required downpayments on houses; the absence of scholarships at universities; a system of postal savings banks authorized to pay interest rates higher than rates available elsewhere on deposits, and tax exemptions on interest on postal savings up to a certain level (14 million yen in the early 1980s); a bonus-pay system of compensation in Japanese corporations; and very high interest rates (with no tax deductibility of interest paid) on consumer loans .22

Together, these measures discouraged consumption and encouraged saving. In addition to providing a large pool of capital, the system also controlled the cost of raising it. Households were paid low rates of interest on the savings they put into banks,[23] but rewarded by the tax benefits, or ''maruyu,' for doing so. Securities markets were tightly controlled so as to concentrate household savings in postal

17Personal communication with Ronald Dore, Imperial College, University of London; and Edward J. Lincoln, The Brookings Institution, March 1989.

18Aron Viner, *Japanese Financial Markets* (Homewood, IL: Dow Jones-Win, 1988).

19Personal communication, OTA staff with Mr. Kitamura, Financial Bureau, Ministry of Finance, Tokyo, Japan, Mar. 13>1989.

20The following discussion of Japan's financial system depends heavily on the following sources: Viner, op. cit.; Andreas R. Prindl, *Japanese Finance: A Guide to Banking in Japan (New* York, NY: John Wiley & Sons, 1981); Philip A. Wellons, ''Competitiveness in the World Economy: The Role of the U.S. Financial System,' in Bruce R. Scott and George C. Lodge, U.S. *Competitiveness in the World Economy* (Boston, MA: Harvard Business School Press, 1984).

21 Wellons, op. cit., p. 361. Another set of institutions, equally important, gave Japanese firms preferential access to the domestic market, helping to assure a demand for the products of Japanese industry without ruinouscompetition from (at that time) abler foreign competitors. Japan's trade policies and their relation to industry policy will be discussed in the final report of this assessment of Technology, Innovation, and U.S. Trade.

22To be specific, a change in the rules governing consumer finance companies-known as *sarakin*—in 1985 reduced the maximum rateon consumer loans from 109.5 percent per annum to 73 percent, and set a maximum of 10 percent of annual salary of 500,000 yen to the amount one customer could borrow. Source: Viner, op. cit., p. 339. For an explanation of how the bonus-pay system promotes savings, see Abegglen and Stalk, op. cit., p. 1%.

23Banks did not pay as hi@ interest rates as postal savings, but the upper limit on the amount of any one postal savings account, the trouble of keeping several accounts, and the fact that company employees are often encouraged to use the company's main bank or an affiliate, kept some household savings accounts in banks.

savings and in banks, so that banks, with their controlled interest rates, did not have to compete for savings by paying high rates of interest to depositors, and thus narrow their profit margins. Interbank transfers of funds were also handled so as to minimize the eventual interest rate that industry paid. The result of all this control was that money was channeled from households through several banks to corporations, at rates that greatly favored industrial investment and expansion at the expense of consumption. The extent of the transfer was huge. According to one estimate, if these measures lowered the interest rate to business by 2 percentage points in 1971,800 billion yen was transferred from households to businesses in that year-money that, under free market conditions, would not have gone to the corporate sector.[24]

Both commercial and governmental banks lend money to Japanese corporations, but the distinction between them is rather more blurred than is the case inmost other industrialized nations. The commercial banks include the large city banks, which specialized in lending to large, blue chip corporations during the high growth period;[25] regional banks, which tend to lend to small and medium-sized companies; the Bank of Tokyo, technically a city bank, but the only one that could make foreign exchange transactions until World War II, and is still a specialist in foreign trade financing and foreign exchange; trust banks, which specialize in managing pension funds; specialized banks; the postal savings system; and long-term credit banks created in the 1950s and 1960s by government to make long-term funds available for industrialization. These last (which include the Industrial Bank of Japan and the Long Term Credit Bank) were able to provide funding to companies even when there were severe liquidity shortages, thus reducing the vulnerability of Japanese firms to ordinary fluctuations in economic conditions.

The government exercises control over and through the banks in many ways. First, interest rates have been tightly regulated since 1947, when the Temporary Interest Rate Adjustment Law was passed.[26] By 1986, after 2 years of steps toward deregulation, about 80 percent of deposits in Japan still came under fixed interest rate regulations.[27] Interest rates have historically been negotiated by the Ministry of Finance, the Bank of Japan, and long-term credit banks, the financial institutions most concerned with the competitiveness of Japan's industry. Equity-to-asset ratios have also been extremely low by international standards; they averaged 2.19 percent for the city banks as of March 1986, compared with 5 to 6 percent for U.S. banks.[28] This allows Japanese banks to make low-interest loans both domestically and (lately) abroad.

There are informal controls as well. The Ministry of Finance exercises enormous (though waning) control over all aspects of Japanese finance. Much of this is through so-called administrative guidance, which takes a variety of forms, and can affect behavior at the level of the individual firm or bank. MoF's instructions and desires are not often ignored, even when they are not backed by force of law. Its staff are "the most gifted graduates of the best universities. 29 Like many other powerful Japanese institutions, MoF operates through frequent contact and consensus building; it holds regular meetings with the management of main Japanese banks, influencing the actions of Japanese branch banks in foreign nations as well as at home. When its senior staff retire,[30] many of them accept positions at the long-term credit banks, which were privatized decades ago. According to Viner, ". . . it is neither accurate nor meaningful to describe the three long-term credit banks as private institutions. Their

24Y. Kurosawa, op. Cit., p. 13.

25Both deregulation and the financial success of the large corporations of Japan have encouraged the city banks to look for new kinds of business. Now, with many large businesses financed mainly by bonds, depreciation, and retained earnings, the city banks are turning increasingly to medium-sized businesses for customers. Personal communication with Mr. Tatsuo Takahashi, Manager, Public Relations Division, Japan Development Bank, March 1989.

26The word "temporary" is misleading; the law is still in effect.

27Viner, op. cit., pp. 306-307.

28Viner, op. cit., p. 20*. This low equity-to-asset ratio is typical, despite the fact that the 1954 Banking Act required a ratio of 10 percent. According to Viner, "this level was considered absurdly high by banks and was ignored. "

29Prindl, op. cit., p. 9.

30The term for this is *amakudari*, or 'descent from heaven'—which by itself connotes a status of civil servants that is very different from American experience.

ties with the government are so close that in many respects they resemble auxiliary components of the Ministry of Finance. "

Industrial Policy--Formal and informal controls can be used both systemwide—to advance capital relatively cheaply to firms and away from personal consumption, for example-and in pursuit of more industry-specific goals. The government acts both as a direct lender and as a bellwether for other private sector lenders. Its direct role is small-in 1980, only 5.6 percent of all funds placed in financial institutions in Japan reached business directly from governmental institutions,[31] and long-term credit banks provided another 5.2 percent. But this governmental role is more powerful than its modest funding would suggest. According to Wellons, "few dispute that private lenders in Japan treat this lending as a sign that the firm or project has government support, which would reduce the risk of the credit. " Many Japanese sources agree. According to Kurosawa,

> The government also helped to reduce risk; MITI established specific goals and initiated investment for companies, and when necessary, adjusted the order [of] which group of companies should invest first and which next *(Rinban Toshi).*[32]

One way the Japanese Government primes the private lending pump is through the Japan Development Bank (JDB). When motor vehicles were chosen for rapid development in the 1950s, and electronics in the 1960s and 1970s, the Japanese companies were generally far behind American and European companies in technology, and financial returns from heavy investments in those industries were therefore quite uncertain. City banks, with much of the lendable capital, might have been wary of making heavy investments in such industries, but were reassured by JDB's lending. Throughout the postwar period, JDB loans have been among the most important sources of funds for new equipment acquisition in manufacturing. In fact, even in the 1980s, long after the end of any real capital scarcity in Japan, about one-fourth of JDB's funds still go to manufacturing.[33] Where JDB lends is, in turn, decided by a variety of government departments, with strong participation from MITI, and its lending is meant to help major strategic industries directly.[%]

Financial support for both industry as a whole and strategic industries in particular has been a crucial element of Japanese industrial policy, but it is by no means the only one. Government support takes a variety of forms, including preferential access to the Japanese market,[35] support for research and development, market segmentation among domestic firms, and control of foreign investment. With such a panoply of tools at hand, and the demonstrated willingness to use them to support development of industries, government can pack a powerful punch with a relatively modest direct financial role.[36] Also, the variety of available tools helps to make up for weaknesses in the use of any one. For example, pump priming alone would not have induced Japanese banks to invest in certain sectors where the expected returns were especially low; it was decisive, however, where both expected returns and risks were high.[37]

The government's control over the financial markets is lessening. Many Japanese financial institutions see narrowing opportunities for growth

31These institutions include the Japan Development Bank, the Japan Export-Import Bank, and agencies to finance small and medium-sized business. Source: Wellons, op. cit., p. 380.

32Y. Kurosawa, op. Cit., p. 16.

33Robert J. Ballon and Iwao Tomita, *The Financial Behavior of Japanese Corporations* (Tokyo: Kodansha *International,* 1988), p. 37.

34Personal communication with Mr. Kitamura, Ministry of Finance, op. cit., and Ballon and Tomita, op. cit.

35This is not total market protection, as is sometimes claimed; however, access to Japan's markets in targeted industries is carefully controlled and limited, as are opportunities for direct foreign investment and direct investment abroad. Preferential access allows Japanese producers to sell goods in Japan at higher prices or of lower quality than they could if foreign products were allowed unlimited access. Barriers to foreign competition are usually phased out once the Japanese industries have grown to be formidable competitors. However, we are now beginning to see Japan resorting to voluntary restraint agreements in industries that are under pressure with the rise of the yen and the growing competence of other Asian competitors. A more complete discussion of these mechanisms will appear in the next and f-real, report in this OTA assessment.

36Although their number is declining, there are experts who dispute the degree to which Japan's industrial policies have been responsible for the postwar success of her industries. Clearly, other nations have used tools similar to Japan's without the same results, and Japan herself has demonstrated remarkable ability to develop industries in earlier periods when policies were quite different, as in the decades following the Meiji Restoration in the late 19th century. Thus, more than industrial policy is responsible for Japan's recent performance. However, industrial policy has been and remains a critical factor in Japan's development, as will be explained more fully in the next and final report in this OTA assessment.

37Sakakibara Eisuke, Robert Feldman, and Yuzo Harada, The *Japanese Financial System in Comparative perspective, study* prepared for the Use Of the Joint Economic Committee (Washington, DC: U.S. Government Printing Office, 1982).

domestically, as prosperous Japanese firms are increasingly able to finance themselves, or have more freedom to choose among domestic and foreign financing options. International pressure has also been a factor forcing liberalization of Japanese financial markets. However, it would be a mistake to regard Japan's financial market as open—the deregulation is proceeding deliberately, so as to avoid major shocks--or to discount the advantage that tight controls gave to Japanese industry during the postwar period through the early 1980s. Without the deliberate channeling of capital away from personal consumption and towards industry-particularly those that were targeted-it is unlikely that so many Japanese industries would be so prominent on the international scene as they are now. It is also prudent to assume that, if Japanese manufacturing comes under increasing international pressure, the financial system is capable of mobilizing quickly in response.

Corporate Finance-It is well established that Japanese firms rely more heavily on external financing-both debt and equity—than American firms, and that the reliance was greater in the past than it is now. Debt financing in particular has played a greater part in corporate finance in Japan than in the United States (until very recently) and other western industrialized nations, and it still does so today, even though the percentage of equity financing is growing in Japan.

Precise figures are somewhat deceptive, as many critics have pointed out. The gearing ratios[38] reported are based on the book value of companies' assets, which are reported at historic cost. Inflation, especially the run-up in the value of property and land in Japan, tends to understate asset value and thus overstate gearing ratios. However, even when the figures are corrected to reflect more realistic measures of Japanese (and American) fins' asset values, gearing ratios in Japan were still roughly twice as high as those in the United States only a few years ago. In 1981, for example, Japanese gearing ratios were estimated at 0.56 to 0.62; American at 0.28 to 0.30.[39] Japanese dependence on bank financing is also high compared with that of European nations. American companies have depended much more heavily on retained earnings (internal financing) and equity. This remains true even with modest moves away from debt as a source of new funds in Japan and increases in debt in America,[40] the latter resulting mostly from takeovers and leveraged buyouts to defend against the possibility of takeovers.

Japanese reliance on bank financing, particularly when capital was much less available there than it is now, underlines the importance of low interest rates in Japan. It also means that fins' relationships with banks are more important than their relationships with shareholders, compared with the United States (and much of Europe). As long as Japanese banks_ are sympathetic to the need to make long-term investments with little immediate return, firms are more likely to make such investments. This would be true even if Japanese fins' relationships with their shareholders were the same as those of American fins; however, Japanese shareholders are also more sympathetic to the long-term interests and performance of Japanese firms than in short-term financial gains, compared with American shareholders.[41] In short, while the structure and regulation of Japanese finance would alone lead to the conclusion that Japanese firms are better able to make long-term, relatively heavy investments than American firms, the nature of the relationships between capital providers and firms supports this conclusion as well.

Japanese banks-including both commercial banks like city and regional banks, and government institutions like the Japan Development Bank-are more involved with their clients than are American banks. This is true at every step of the process, from screening to monitoring of firm performance.[42] To begin with, Japanese firms usually have a special relationship with one bank, a system known as the main-bank system, and this relationship is an important part of the risk-sharing that allows Japanese firms to enjoy or act like they have lower capital costs. Kurosawa characterizes the main bank system this way:

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[38]Gearing ratio is defined as the sum of short- and long-term liabilities divided by total assets.

[39]Figures reported in Jenny Corbett, ''l,n~rnation~ Perspectives on Financing; Evidence from Japan,' *Oxford Review of Economic Policy*, vol. 3, *No.* 4., p. 34.

[40]Ben Bernanke, "Testimony on corporate debt," mimeo, May 25, 1989.

[41]This is largely due to the institution of stable shareholding, as is explained later in this chapter.

[42]This conclusion, and much of the following discussion about banks' relationships with firms, depends heavily on Corbett, op. cit., passim.

> *The* main bank almost always has the largest share in such business relationships as lending, shareholding, trusteeship of bonds, deposits, and so on. It gives special priority to the client firms in credit rationing, and in the case of a severe slump or bankruptcy crisis, coordinates the responses of other lending financial institutions and acts as a mediator and supporter for the clients' survival. Consequently, it is essential for the main bank to monitor the firm, and for the other banks the actions of the main bank act as a signal. If the actions of the main bank remain unchanged, there are no problems in the fire-t. The main bank's additional loans in effect guarantee the security of the other banks' loans.[43]

Differences begin with the way they screen potential borrowers. For example, city banks are less concerned about debt/equity ratios and are more sensitive to the firm as a going concern (rather than as a default risk) than are non-Japanese banks. The screening is extensive, so when a city bank takes on a client it is generally considered a good credit risk by others. Part of the screening is done by the city banks, but they are also able to rely on extensive screening by the Japan Development Bank and the Industrial Bank of Japan (IBJ).[44] There is some genial disagreement between these two institutions as to which developed the screening procedures both employ—both lay claim to it—but in any case, it is thorough. According to IBJ, the screen consists of increasingly smaller sieves. First, the Industrial Research Department (IRD) develops information on specific industries, examining in detail possibilities for growth and international competition. The IRD also examines new sectors and technologies, such as biotechnology and superconductivity, for their eventual commercial possibilities. Once industry prospects are understood, the Credit Department screens individual companies. If IBJ accepts a company, that is a powerful signal to other financial institutions of the company's creditworthiness, and a pattern of heavy lending to any particular industry or sector is also a bellwether.

There are several reasons why the close ties between main banks and their corporate customers could lead to a longer term outlook on the part of businesses, and possibly even to better decisionmaking than in countries like the United States or England, where ties between banks and the companies they lend to are more frequently arm's-length. As noted above, the close relationships between city banks and their customers are based on massive amounts of information, always a good basis for sound advice and decisionmaking. The city banks, along with other major Japanese financial institutions like JDB, have become powerful information brokers, and their ability to gather and process information about businesses and business conditions in a variety of industries around the globe probably exceeds that of all but the very largest corporations. Banks can therefore serve as important sources of information for strategic and operating decisions for their closest customers. This assistance on the part of banks is influential in encouraging companies to focus on longer term goals in Japan and Germany.

Another difference between Japanese and American bank lending is that loans from city banks are much more likely to be long term. According to the Bank of Japan, about 40 percent of Japanese corporate borrowing had a maturity of more than a year, compared with only 19 percent in the United States, as of 1985. However, the longer maturities of many Japanese loans are not exceptional compared with France and the United Kingdom (where about 40 percent of loans are classified as being long or medium term) or Germany (where about 60 percent of corporate loans are long term).[45]

Finally, it is well established that the conditions of loans are changed when economic conditions change in Japan. Although this practice is also common in western industrialized nations, the kinds of changes made are different. Corbett points out that a shortening of the term of a loan would be expected if a firm gets into trouble; yet in Japan loan maturities have lengthened at the same time that bankruptcies increased. With heavy investments of both capital and prestige in the successor failure of their clients, Japanese (and also German) banks are far more likely, in a crisis, to extend additional financing and assistance before pulling the plug than

[43] Y. Kurosawa, op. cit., p. 18.

[44] The Industrial Bank of Japan is one of Japan's three long-term credit banks, and it is usually described as the most prestigious of all Japanese private banks. Its purpose is to provide long-term capital to private corporations, with priority given to industries that are part of the government's industrial policy.

[45] Bank of Japan, *Economic Statistics Annual*, various years; and Corbett, Op. cit., p. 42.

an American or a British bank.[46] Japanese banks often forgive payments on debt principal during tough economic times, or restructure debt in order to allow firms additional options to overcome their problems.[47] While some firms do eventually go bankrupt or are forced to restructure severely, banks explore many other options with their clients (often at great cost to themselves) before declaring loans in default. Prindl tells the story of Ataka, the fourth largest Japanese trading company in the early 1970s.[48] It got into trouble over excessive credit extended to a refinery in Canada, and eventually had to merge with another firm, C. Itoh. However, $370 million in uncollectable receivables were absorbed by its house banks, Sumitomo and Kyowa. This was possible, in part, because of the widespread belief that no large bank would be allowed to fail. Indeed, in 1986, Japan had its first bank failure since World War H, and that was a result of 'massive, long-term corruption. This situation is changing, like so much of Japanese business. According to Viner, "banks have been informed that they can no longer expect central bank rescue in the event of a liquidity crisis."[49] So far, this new policy has not been tested.

Even the promise of government support does not seem adequate to explain why Japanese banks are more willing to go the distance with their clients, as long as there is some chance of maintaining the company in business. In part, it is because the main bank's relationship with a client company goes far beyond a loan. Companies generally encourage their employees to deposit their savings in their main bank, and deal with the main bank or its affiliates for life insurance and managing the pension fund. In addition, the main banks, in return for bearing some of the risk of the company's long-term investment, are privy to a great deal of information about the company, and are allowed to take part in its management should it get into trouble. Main banks often accept deferment of payment on principal and interest if a client gets into trouble,[50] and will coordinate rescue funds from other banks. In addition, however, they investigate whether the company can be restructured to get it out of trouble, and often draw up the restructuring plan.[51] Corbett points out that exchanges of personnel at both senior and junior levels between banks and large firms (and government ministries) are common.[52] Banks sometime suggest changes in strategy when evaluating a customer's request for a loan, and make more forceful suggestions of strategic changes when a firm gets into trouble.

The kind of involvement that large banks maintain with their customers resembles that of preferred stockholders more than creditors, according to Kurosawa. Preferred stock may have a fixed dividend, but if profits are insufficient to support it, the rate will be reduced and carried over.[53]

But what about actual equity holders? Here, too, there are different relationships in Japan. Most large Japanese firms belong to groups known as keiretsu, which translates as "group arranged in order. " These are companies that have primarily been associated with one city bank, and hold relatively large amounts of each other's stock—1 to 3 percent, typically, of the stock of each other member of the group. The result is that a majority of shares of all members are held by other members of the same keiretsu.[54] Japanese city banks also typically hold stock in the companies they provide credit to, with the maximum amount now limited to 5 percent. Finally, although intra-keiretsu shareholding is decreasing, a majority of stock in Japanese corporations is still typically held by corporate and other institutional investors, rather than by individual shareholders. As of 1988, 69 percent of all shares listed on the Tokyo exchange were held by domestic institutional investors—19 percent by banks, 13 percent by life insurance companies, and 26 percent by other corporations—while 25 percent was held by

[46] Corbett, op. cit.

[47] Personal communication with David HI,@ Whittaker, 1988; Flaherty and Itami, op. cit., p. 144; Corbett, pp. 46-51 passim.

[48] Prindl, op. cit., p. 64.

[49] Viner, op. cit., p. 196.

[50] This should not be regarded as a distant possibility, Ballon and Tomita point out that, "more often than not, [the] bank at some point in time has had to stage a rescue operation for its major clients with the cooperation of other parties concerned," Ballon and Tomita, op. cit., p, 60.

[51] Y. Kurosawa, op. cit., pp. 19-20.

[52] Corbett, op. cit., p. 45.

[53] Y. Kurosawa, op. Cit., p, 20.

[54] Viner, op. cit., p. 2.

individual Japanese stockholders and 6 percent by nonresidents.[55] In contrast, 57 percent of U.S. equities were held by individuals as of mid- 1989.[56]

More important than the pattern itself is the character of equityholding in Japan. Until the early 1970s, it was virtually impossible for more than a tiny trickle of foreign capital to find away into Japan without the express permission-indeed, sponsorship--of government. In 1971, the door was opened a crack through revision of the Securities Exchange Law, and along with the liberalization came mounting concern that foreign companies would take over Japanese corporations. To prevent that, Japanese companies—at the urging of government—resorted to a system known as stable shareholding.

Stable shareholders are Japanese nationals who can be counted on to keep their shares, no matter what happens to their price. It is a primary duty of financial officers of corporations to find stable shareholders. According to Ballon and Tomita,

> When a capital increase is planned, financial executives usually visit the major shareholders who might be willing to subscribe to new shares and request their cooperation in purchasing the new shares at par while retaining both old and new shares. However, a request for further subscription of shares frequently implies a favor in return. . . the firm may at this time confirm its friendly relationship with the bank by promising (albeit unwillingly) to buy more bank shares.[57]

Stable shareholding has had the direct result of permitting companies to keep a longer term view in their capital investment. Stable shareholders prefer retaining earnings to receiving high dividends, permitting the company that issued the stock to reinvest its earnings, This reinvestment, in turn, is viewed as directly contributing to higher share prices. Since stocks are carried on their owners' books at purchase price, rather than market value, the rapid increase in share value has allowed Japanese banks and corporations to carry substantial hidden reserves. These hidden reserves are the utility infielders of Japanese accounting: they can be used to manipulate the reported levels of profit, and thereby, taxes and dividends. For example, if the company has a loss and needs to show a small profit, it can sell a portion of its investment securities, whose book value is usually significantly underreported. Often, it sells these to an affiliate or another stable shareholder, and expects in its turn to pay the same consideration to its affiliates when needed.[58] The amount of hidden reserves is staggering: at the end of March 1988, the hidden reserves of securities of the 13 city banks alone totaled $229 billion.[59]

Stable shareholding has served the needs of the Japanese economy admirably. It permitted long-term investment at a time when Japan's companies were much more vulnerable to foreign competition than they are now. It has helped Japanese companies to continue expansion and market share-building during the various economic upheavals that paralyzed their competitors—through energy shocks of the 1970s, the recessions of 1974 and 1982, and through *endaka* in 1985-86. Most observers expect stable shareholding to continue for the foreseeable future, although it will face increasing challenges in the years ahead. Financial liberalization in Japan and the expansion of Japan's business and financial ties around the world have made it more vulnerable to outside economic uncertainties. While its recovery during the postwar period has been robust, this new international exposure could well reduce its power in the future. The high yen, too, has put the whole economy on a more precarious footing. Some of the advantages Japanese firms receive have narrowed or disappeared, and strong competition from a new set of industrializing nations has left Japanese manufacturers with less ability to ride out a prolonged downturn. In a downturn, stable shareholding might start to unravel, as companies in trouble draw down their hidden reserves. The demise of this institution is unlikely without a major recession, and not certain even with one; however, if it does happen, the system is likely to come apart rapidly.[60] That, according to Ballon and Tomita, "would have

55 Hideo Ishihara, ''Japan's Compliant Shareholders, " *The Asian Wall Street Journal Weekly,* June 13, 1988, p. 17.

56 Securities Industry Association data, compiled from *Flow of Funds Accounts,* Federal Researve Board. This *total is down* from 65 percent in 1985 and 85 percent in 1%5.

57 Ballon and Tomita, op. cit., p. 52.

58 Ballon and Tomita, op. cit., p. 202.

59 Y. Kurosawa, Op. Cit., p. 20.

60 Personal communication, OTA staff with Kimihide Takano, Senior Analyst, Corporate Division, The Nikko Research Center, Ltd., Tokyo, Mar, *22, 1989.*

profound repercussions on the stock market and the Japanese economy as a whole."[61] It would tend to shorten the perspectives of Japanese managers and firms, making them more like American fins. However, given the pervasive effect of administrative guidance from the Ministry of Finance, it seems unlikely that the Japanese financial market will behave a great deal like that of the United States anytime soon.

In sum, a network of policies, practices, and relationships acts to support heavy investment in long-term performance in Japanese industry by spreading risk. In contrast, American firms must carry more of the risk of such investments by themselves. While changes are occurring in the Japanese financial market, the backlog of more than three decades of such advantages has been highly effective in putting Japanese firms in the secure positions they now hold, relative to American and European competitor. Even if the changes were dramatic and rapid (which they are not) these advantages would not disappear quickly. It may well be that alterations in the way American managers are *taught* **to think** about business could foster a more positive attitude toward long-term investment, particularly in improved technology. But it is the rules under which they must operate rather than their education that is the principal influence on how U.S. managers view long-term investment.

Even with changes in the rules, however, there will be outliers. High capital costs have hobbled but not crippled American firms in international competition; some firms are able to make substantial investments in technology development for many years. If a firm exploits its R&D effectively, such investments are rewarded, not penalized, by equity holders. But now, with increasing competition, more firms are forced to choose between supporting profit margins or stock prices and postponable expenditures like R&D.

Some long-term investments pay off, and some don't. We should not expect that risk-sharing will necessarily result in longer term investment across the board in America, or that every long-term investment will be successful. However, without some changes in the financial rules of the game, American companies will continue to focus mostly on short-term profit, to their detriment in international competition.

THE AMERICAN FINANCIAL MARKET

The problem for America is not only that Japan's capital costs are lower than those of the United States, or that Japan's providers of debt and equity capital are content to take more of their rewards as capital gains rather than as cash payments. Among the developed nations, Japan goes unusually far down these paths. America is, for the most part, at the other end of the scale. Our capital costs are high not only relative to Japan's, but relative to those of many European countries as well, and they are high in real terms, compared to what they were in the 1960s and 1970s. Institutional investors are, if anything, more insistent on receiving short-term financial gains than they have been, and they have powerful tools to use if their interests are not addressed. Rather than mobilizing its resources to support American manufacturing during its difficulties, the United States often seems indifferent to or contemptuous of the nation's manufacturers. The problems of manufacturers, we often say, are self-generated; manufacturing is badly managed, and badly managed firms ought to fail, or change hands. The contrasts with Japan, and with Europe as well, are great.

Some—not all--of what we attribute to bad management is simply a matter of intelligent people playing by the rules. If our interest rates are such that American managers can prudently invest $0.37 in return for $1.00 in 6 years, while a Japanese manager could invest $0.66 for the same return,[62] we would expect to see about half as much long-term investment in America as in Japan. If stockholders evaluate a company's performance on the basis of quarterly or half-yearly reports of profit, we would expect managers to emphasize short-term profits, even when it raises possible conflicts with longer term investment. And if showing a profit for shareholders is one of the most important factors in the survival of a business, we should expect to see financial specialists wielding more power in compa-

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[61] Ballon and Tomita, op. cit., p. 53.

[62] These figures reflect the actual cost-of-capital difference of Japan and America, according to one calculation. See James M. Poterba, "The Cost of Capital Consequences of Curbing Corporate Borrowing,' Testimony before the committee on Ways and Means, U.S. House of Representatives, May 16, 1989.

nies than in nations where share price is a less pressing daily concern to company managers. The preoccupation with finance and short-term share price performance was reinforced by the wave of mergers and acquisitions American business experienced in the 1980s. Rather than moving toward an environment more conducive to long-term investment in the development and use of outstanding technology, the U.S. system raised the hurdles.

Another complicating factor is instability in the financial environment. Federal decisions affecting the value of the dollar and interest rates take business competitiveness into account only tangentially, if at all; yet such changes can have profound effects on the ability of businesses to make prudent long-term investments. Again, Japanese policies contrast sharply. U.S. Government support for long-term research, development and investment has also been somewhat shaky, leaving businesses that invest in such projects vulnerable. For example, the Administration sent confusing signals about its support for technology development in semiconductors and high definition television in 1989. Even if the modest support for R&D in these areas is continued, the unreliability of Federal commitment to such programs could make industry wary of such ventures.[63] Another example of the inconstancy of Federal efforts to promote technology development and diffusion is the impermanence of tax measures that favor capital spending or R&D.

In short, America's financial environment is generally unfavorable to long-term investments in technology development and diffusion, and government actions that mitigate the effects of this unfavorable environment have lacked commitment.

The Decline in Savings

Nations must continuously invest in productive assets-plant and equipment, people, and technology development—to sustain investment and living standards. Investment funds come from saving, domestic and foreign. In the 1980s, an increasing proportion of U.S. investment has come from foreign saving, because U.S. savings rates have fallen.

In the 1970s, net national saving (the percent of national income saved by business, government, and households) averaged 7.9 percent. Of this, 96 percent was invested domestically, and 4 percent was invested abroad. In the 1980s, savings rates dropped, and by the middle of the decade-1985 to 1987—net national saving dipped to 2.1 percent before rising to just above 5 percent in 1989. Net domestic investment (the percent of national income invested) dropped to 5.7 percent, lower than in the 1970s but greater than the amount of investable capital provided domestically. The United States made up the difference by becoming a net importer of investment funds, borrowing $417 billion from abroad over the 1985-87 period.[64] To attract savings from abroad, the United States has had to raise interest rates, or the return to investors. Importing capital allowed the United States to invest more than its own savings would permit, but it also raised the price of domestic investment. This means that improving and replacing productive assets and technology for U.S. firms became more expensive in the 1980s. A nation trying to keep pace with well-financed and technologically sophisticated competition can ill afford this.

The decline in savings occurred across the board. The sharpest change in the 1980s was a decline in government saving, manifested by budget deficits at the federal level. Falling household and business savings contributed to the decline as well. The Federal budget deficit resulted from a tax cut, which slowed the growth of revenue, and from increased outlays, principally for defense.

The reasons behind falling household savings are less obvious. Many explanations have been advanced for this drop-and conversely, the rise in consumption as a percent of national income—but there is little consensus on which are most significant. Some analyses attribute part of the decline to high interest rates, which made it possible for corporations to decrease contributions to pension

[63] In late 1989, rumors of an Administration proposal t. kill funding fo, Sematech in the fiscal year 1991 budget surfaced. The nunor arose concurrently with Administration proposals to shut down the Defense Manufacturing Board, and an OMB proposal to reduce DARPA funding for HDTV. While the Administration eventually denied any plan to kill funding, the rumor was widely believed and taken seriously by much of the electronics industry. See ''Administration Charged With Seeking Funding Cuts for Sematech, Other Projects,' *International Trade Reporter, Nov. 15,1989,* pp. 1481-1482; and Lucy Reilly, "Death Knell for Sematech?'' New *Technology Week, Nov.* 6, 1989, p. 1.

[64] George N. Hatsopoulos, Paul R. Krugman, and James M. Poterba, *Overconsumption: The Challenge to U.S. Economic Policy (New* York, NY and Washington, DC: American Business Conference and Thermo Electron Corp., 1989), pp. 6-7.

funds (these are included in household savings). The jury is out on the effect of demographics. Some think the baby boom was a major factor in increasing consumption rates: since young people typically save less than the middle-aged, they expect personal savings rates to rise as the baby boomers mature. Others dismiss demographics as having little explanatory power. Another often-cited argument is that gains in wealth in the 1980s--capital gains on corporate equities and homes----encouraged consumption. If people feel richer because their assets are increasing, goes the argument, they feel less need to save. On the other hand, since real wages and salaries dropped during the 1980s, falling savings may reflect attempts to keep up consumption patterns in the face of (for most families) declining incomes.[65] Another theory is that the propensity to consume may have been fueled by the easy availability of consumer credit.[66]

The enormous increase in Federal Government debt and the fall in household savings rates were enough by themselves to force a curtailment of capital formation, or a switch to capital imports, or both. The decline in business saving has been less remarked, but is important for two reasons. Between the mid-1960s and the late 1970s, business saving—measured in national accounts by the retained earnings of corporations-fell from 4.5 percent of GNP to 2.75 percent. By the mid-1980s, business saving fell still further, to 1 percent of GNP.[67] Unlike the ballooning Federal deficit and falling household savings, the decline of business savings is long-standing, and cannot be fully understood in terms of the events of the 1980s alone. Nonetheless, the depression of business savings to the lows of the 1980s is part of another change in the financial environment-that is, mergers and acquisitions—that limits the willingness of American companies to make long-term investments.

Mergers and Acquisitions

Mergers and acquisitions are a normal feature of the U.S. financial landscape, and ordinarily not a controversial one. Occasionally, though, merger and acquisition (M&A) activity heats up, as it did in the 1980s, provoking debate and examination. M&A activity has raised many questions including those of basic efficacy (are mergers and acquisitions really an effective managerial disciplinary force, for example) and effect (do mergers and acquisitions generally improve long-term productivity, or produce outcomes as desirable from society standpoint as from target shareholders'?). None of the questions are resolved. Even questions that are somewhat peripheral to the whole debate—such as the effect on managers' willingness to undertake longer term investments in technology development and diffusion—are hotly debated. While there is a growing body of research and empirical evidence on the causes and consequences of M&A, there are few points of consensus in the argument. But it is clear that the takeover wave of the 1980s is a special feature of the American financial environment, much more prominent here than in any other nation. The length of the following discussion is not meant to imply that M&A is the only, or even the major, factor that causes American managers to focus strongly on short-term profit, but M&A does intensify the pressures of the American financial environment, characterized by high interest rates and capital costs and macroeconomic instability.[68]

Briefly, the argument goes as follows. One point of view-often articulated by businessmen—is that corporate raiders have forced a preoccupation with short run performance that has disrupted business planning. With access to new capital instruments (junk bonds), acquirers can afford to pay inflated prices to get controlling interest in their targets. The first defense against potential raiders, therefore, is to keep the stock price high enough to fend them off. Since stock prices can fall significantly on disappointing quarterly profit performance, business man-

[65] Katherine Gillman and Joy Dunkerley, "Is the Middle Class Shrinking?" *Futures*, April 1988.

[66] The following sources discuss reasons for falling savings rates: Barry P. Bosworth, ' 'There's No Simple Explanation for the Collapse in Saving,' *Challenge*, July-August 1989, pp. 27-32; George N, Hatsopoulos, Paul R. Krugman, and James M. Poterba, *Overconsumption: The Challenge to U.S. Economic Policy* (Washington, DC: American Business Conference, 1989); David E. Bloom and Todd P. Steen, "Living on Credit," *American Demographics*, October 1987, pp. 22-29; and William D. Nordhaus, ''What Wrong With a Declining National Saving Rate?' *Challenge*, July-August 1989, pp. 22-26.

[67] Nordhaus, op. cit., p. 23.

[68] The United States is not unstable compared t. most countries, but the American financial environment for business is less stable than that of either Japan and West Germany, our premier international competitors.

agers must focus on keeping short term profits at acceptable levels. This, in turn, exaggerates the already short-term planning horizons of American business.[69]

In some cases, more drastic steps maybe taken to fend off a potential takeover, such as taking the company private by means of a leveraged buyout (LBO), or implementing some kind of "poison pill" defense. While these strategies can keep the company from changing hands, the effects on planning horizons can, ironically, be no friendlier to long-term investment and planning. In the case of a defensive LBO, the company exchanges equity for debt, making it safer from raiders but harder pressed to maintain cash flows. Debt payments must be made, while dividends can be postponed during thin times. Cash flows that could have been invested in research and development, plant and equipment, or other long-term projects must be at least partly dedicated to paying interest and debt retirement; so companies may defer long-term projects in favor of meeting their short-run obligations.[70]

Current concern is spurred by the fact that the availability of high-risk, high-return bonds has subjected many more companies to the threat of a takeover than in the past. Junk bond financing can turn even relatively small operators into potential raiders, and even large companies are not immune from the possibility of a takeover. Any company that appears undervalued may be fair game.[71] Moreover, a company's value to a raider can seem inordinately high to many business managers;[72] company managers feel pressed to keep their stock price above even inflated asset value.

The foregoing argument raises two questions. First, it is difficult to accept at face value the contention that a price can be too high if a willing buyer agrees to pay it. The difference between managers' estimation of the real value of their companies and that of potential acquirers may therefore be that outsiders can see higher yielding opportunities for managing companies' assets than managers do. Experts hold divided opinions on whether acquisition prices are too high.

The concern implicit in the arguments of many businessmen is that equity markets consistently undervalue long-term investments. If the resulting stock prices do not fully reflect the companies' investments in future output, then perhaps acquisition prices are *not* too high, but represent a more realistic appraisal of long-term company value. Here, too, there is no consensus of expert opinion, but it should be pointed out that there is no necessary inconsistency here: while ordinary stock prices may be too low, acquisition prices may be too high.[73]

The opponents in the debate view debt very differently. Those who see takeovers and mergers as a necessary disciplinary force on management see the higher debt levels that result from much of the current takeover activity as keeping managers from squandering corporate assets on less productive ventures.[74] Others regard the high debt that often results from a hostile takeover, or a defense against one, as a ball and chain hampering companies' abilities to invest, particularly in long-term ventures like R&D. The pressure of high debt load is expected cause many defaults or bankruptcies in a recession. Even without a recession, however, the junk bond market is troubled; in 1989, corporate bond defaults were up 136 percent over 1987, largely due to defaults on junk bonds.[75]

Most of the evidence indicates that the *direct* effect of all kinds of M&A activity on R&D expenditures or intensity (R&D as a percent of sales) is small or negligible. Bronwyn Hall, examining approximately 250 manufacturing acquisitions be-

@John C. Coffee, Jr., Louis Lowenstein, and Susan Rose-Ackerman, *Knights, Raiders and Targets (New* York, NY: Oxford University Press, 1988), pp. 34.

70For a brief summary of the arguments on both sides of the controversy, see Robert R. Miller, ''The Impact of Merger and Acquisition Activity on Research and Development in U.S.-Based Companies,' contractor report to OTA, November 1989. The report is a summary of interviews with R&D directors of 19 firms with a variety of M&A experiences. Some had undergone friendly mergers, some hostile takeovers, some leveraged buyouts, and a couple had no recent experience with M&A.

71 Miller, op. Cit., p. 3.

72Warren E. Buffett, Michael D. Dingman, and Harry J. Gray, with Louis Lowenstein, Moderator, ''Hostile Takeovers and Junk Bond Financing: A Panel Discussion," in Coffee, et al., op. cit., pp. 10-27.

73Coffee, et al., op. cit., p. 4.

74Miller, op. cit., p. 6.

75Richard D. Hylton, "Corporate Bond Defaults Up Sharply in '89, " *The New York Times,* Jan. 11, 1990.

tween 1977 and 1986, concludes that the post-acquisition R&D intensity of the firms was about the same as pre-acquisition; moreover, the R&D intensity of the post-acquisition firms was not different from the R&D intensity of all manufacturing firms during the same period.[76] In addition, there is abroad consensus that R&D-intensive firms are unlikely to be attractive takeover targets, and that the majority of M&A happens in firms that do relatively little research and development.[77]

Some use this kind of evidence to dismiss the possibility that M&A is having corrosive effects on R&D in particular or long-term investment in particular.[78] Yet there is reason for skepticism. First, while much of the evidence supports the contention that the effect of M&A on R&D is small, it is not unanimous. The National Science Foundation examined the R&D spending and intensity of the 200 largest industrial R&D performing companies in 1984-86.[79] These companies account for almost 90 percent of all U.S. industrial research and development. Among the 200 firms were 24 firms that had either merged or undergone an LBO during the period; these 24 accounted for nearly 20 percent of the R&D spending of the entire group of 200 in 1987. The firms that did not undergo restructuring increased real spending on R&D by 5.4 percent, while the 24 firms that were restructured through M&A reduced their R&D spending by 8.3 percent in real (deflated) terms from 1986 to 1987. These overall findings were consistent with comparisons of restructured and unrestructured firms at the industry level as well.[80] The NSF data should be interpreted cautiously-the study spans only 3 years, and some of the reductions in R&D might be elimination of redundant programs in newly merged companies—but they indicate a need for equal caution towards studies that show negligible impacts of restructuring.

One possible reason for inconsistencies between the studies cited above is that not all restructurings are alike. One of the few points of consensus in the debate is that M&A in the 1980s is unlike earlier waves of M&A activity, and is certainly different from the background level of restructuring. Different kinds of restructuring-friendly mergers, hostile takeovers, defensive LBOs, and other management buyouts, for example-would be expected to have different effects on managers' abilities and incentives to invest in R&D and other activities considered discretionary in the short run.

The last wave of M&A activity, which occurred in the 1960s, was characterized by diversification and agglomeration. The 1980s, in contrast, are characterized by so-called bustup takeovers of diversified companies with subsequent selloffs of the components.[81] Hall's study includes many mergers from what could be considered another era--the late 1970s--which may blur the effects observed by the NSF study which focused on the mid-1980s. High debt is closely associated with the bustup takeover. Friendly mergers often have little or no effect on overall corporate debt levels, while hostile takeovers and defensive LBOs, in particular, often leave very highly leveraged companies in their wake. One of the striking effects of the 1980s wave of M&A is the substantial increase in corporate debt attributed to it. According to one estimate, the corporate debt burden was 20 percent higher in 1988 than it would have been without the effects of corporate restructuring.[82]

76These results are summarized in "Testimony of Bronwyn Hall in Hearings on Corporate Restructuring and its Effects on R&D Before the Science, Research, and Technology Subcommittee of the House Committee on Science, Space and Technology, July 13, 1989;" and Bronwyn Hall, "Effect of Takeover Activity on Corporate Research and Development,' Alan J. Auerbach (cd.), *Corporate Takeovers: Causes and Consequences* (Chicago, IL: University of Chicago Press, 1988), pp. 69-96.

77See, for example, Lawrence Summers, "LBO Debt and Taxes," *Across the Board,* April 1989; Hall, op. cit.; and Abbie Smith, "Corporate Ownership Structure and Performance: The Case of Management Buyouts,' *Leveraged Buyouts and Corporate Debt,* Hearing Before the Committee on Finance, United States Senate, Jan. 24, 1989.

78For example, see Joseph A. Grundfest, "M&A and R&D: In Corporate Restructuring Stifling Research and Development?" Address to National Academies of Sciences and Engineering, Academy Industry Program of the National Research Council, Oct. 11, 1989.

79The term "industrial" refers to companies in mining, construction, and manufacturing. The vast majority are in manufacturing.

80Testimony of Mr. William L. Stewart, National Science Foundation, before the Committee on Science Space and Technology, Subcommittee on Science, Research and Technology, House of Representatives, July 13, 1989.

81Lynn E. Browne and Eric S. Rosengren, "The Merger Boom: An Overview," *New England Economic Review,* March/April 1988, p. 23.

82Goldman Sachs, *Financial Market Perspectives,* December 1988, quoted in Lawrence Summers, "Taxation and Corporate Debt,' in U.S. Congress, House of Representatives, *Leveraged Buyouts and Corporate Debt,* Hearing Before the Committee on Finance, U.S. Senate, Jan. 25, 1989. The Goldman-Sachs analysis shows the outstanding debt of nonfinancial corporations as a percent of the gross domestic product of those corporations at 66 percent in 1988, compared with an estimated 55 percent without restructuring.

It is quite possible that high-debt restructuring has a greater impact than friendly mergers on R&D. This proved to be the case in OTA's interviews with 19 manufacturing companies representing a variety of different restructuring experiences. Although the sample was not a statistically valid sample of M&A as a whole, the firms that had increased debt as the result of a takeover or as a defense against a takeover consistently reduced R&D following the event. The reductions may not prove permanent-companies may rebuild R&D as they pay down their debt—but most of the R&D managers of the firms that had cut back also believed their firms' future ability to compete was compromised as a result.[83] Hall downplays the overall importance of R&D cutbacks following LBOs (which invariably results in much higher leverage), citing evidence that most firms that undergo LBOs do no R&D. Also, Hall points out that in her sample of 200 manufacturing acquisitions, 30 were LBOs. Those 30 had very low R&D intensity-on average, 0.4 percent of sales-and accounted for only 1 percent of the R&D done in the private sector in the years 1984-86.[84]

What all this seemingly conflicting evidence may mean is that LBOs as a whole have not directly affected R&D overall by a measurable amount, but that LBOs in large manufacturing firms have resulted in reduced R&D, at least in the short run, because of the pressures of high debt. Indirect support for this conclusion comes from another study. Abbie Smith found that R&D intensity declined in firms that reported R&D expenditures before their LBO, and that sold assets after the LBO. Smith warns against any conclusory interpretation of this result, however, because so few of the firms in the population of LBOs studied reported any R&D at all.[85]

Another complicating factor is firm size. Most service firms and small manufacturing firms perform very little or no R&D. The fact that NSF's top 200 R&D spenders accounted for 90 percent of all industrial R&D is telling. Summers points out that many LBOs occur when the owner-manager of a small establishment approaches retirement, and that these are "almost certainly benign."[86] In another common LBO situation, a company finds that a certain line of business no longer fits into its overall strategy, and makes amicable arrangements with the managers of a division for the sale. Again, these buyouts could be expected to have little or no effect on R&D, either because many of the firms involved do little or none, or because amicable transfer of ownership of a division to its current managers can often be accomplished without the high acquisition prices often associated with LBOs.

Analysts have concentrated more on the effects of M&A on research and development than on its effects on other discretionary expenditures. But R&D isn't the only kind of discretionary expenditure that affects a fro's technology; the other is capital expenditure. There are no clear and consistent answers to questions about the effects of corporate restructuring. Capital expenditure is necessary if firms are to keep up with and advance technology, but like R&D, capital expenditure may be postponed for a short time without long-term material damage to a fro's technological base. The duration and depth of sustainable cuts varies by industry and by firm, but even so, available evidence gives some cause for concern. Smith reports a substantial and significant reduction in capital expenditures as a percentage of sales that occurred in 58 management buyouts between 1977 and 1986.[87] This finding is consistent with anecdotal evidence. For example, consider Houdaille, a machine-tool maker that underwent an LBO in 1979. Pressured by foreign competition and (later) the effects of the 1982 recession as well as its high debt burden, Houdaille cut capital spending as a percent of revenues in half following its post-buyout restructuring.[88] One owner of a machine-tool making business states, "When we hear LBO, we know they're not going to be buying anything."[89]

Most analyses of the consequences of M&A have been confined to measurable direct effects—spending on various activities or overall perform-

[83] Miller, op. cit., p. 14.

[84] Hall, op. cit., p. 3.

[85] Smith, op. Cit. p. 71.

[86] Summers, op. cit., p. 187.

[87] Smith, op. Cit., p. 47.

[88] Max Holland, "How to Kill a Company, " *The Washington Post*, Apr. 23, 1989.

[89] Howard Greis, President, Kinefac, personal communication, NOV. 16, 1989.

ance of companies that have undergone restructuring. Two others should also be considered. First, there are qualitative effects, not readily measurable, on R&D or firm activities. Again, we would expect (and find, according to the limited evidence) that different kinds of restructuring have different qualitative effects. In OTA's interviews, firms that mounted successful defenses against hostile takeovers (leaving the companies with high debt) long-term R&D had invariably been significantly cut back in favor of projects with promise of quicker payoff.[90] Some analysts interpret this kind of cutback as making R&D more efficient, and this is indeed possible in the short run. R&D is by its nature a long-term process, and firms can cut back on new long-term projects without impairing their ability to exploit the results of projects undertaken in the past. So a shift in emphasis toward shorter term projects would be unlikely to show up as detrimental for at least a year or two. But in the long run, it seems unlikely that increasing the focus on short-term projects on the part of American firms will permit them to maintain even their current level of competitiveness.

Friendly mergers, on the other hand, had either little impact on R&D, or effects that would be generally accepted as positive. One example is the purchase of Celanese Corp. by the West German chemical firm Hoechst. Hoechst was interested in expanding its U.S. operations through the purchase of an American firm with strong R&D, and after the acquisition increased Celanese's R&D expenditures by 10 percent annually. Significantly, the new German managers were also more willing to commit substantial resources to long-term projects with less certain payoffs.[91] A similar story was told by the president of Materials Research Corp., a semiconductor equipment and materials company recently acquired by Sony. After the deal was completed, the president was told by Akio Morita, the president of Sony, that he had "essentially unlimited capital," and was no longer obliged to concern himself with quarterly profits. "I can think of projects that take two years, " said Dr. Sheldon Weinig, the president. "It's a wonderful way to live."[92]

It is difficult to make a few cases add up to a strong finding, but the anecdotes about the qualitative effects on manufacturing R&D of different kinds of M&A activity are consistent with quantitative evidence, if the focus is adjusted correctly. In other words, both the qualitative and quantitative evidence suggest the following: in manufacturing firms that have appreciable amounts of R&D, restructurings that result in high debt levels depress R&D spending or intensity, or both, and often shorten the allowable time for completion of R&D projects. Because such restructurings are not common—most happen in firms that do little R&D, and many of them are in service fins-the overall direct effects of M&A on overall national R&D are not yet large, and may never be, particularly as hostile takeover/LBO activity seems to be winding down for now. This does not justify complacency about M&A. NSF's data are disturbing, and will be more so if the highly leveraged companies continue to lag in R&D spending or long-term planning. Additional depression of discretionary expenditures on capital equipment or R&D could well occur in the event of a recession, or perhaps even when growth is less than robust. Such cutbacks, normal in recessions, are more likely when companies are highly leveraged.

Finally, the indirect effects of M&A must be considered. The 1980s added a new wrinkle to the takeover enterprise: the expansion of the pool of potential raiders. In the past, in most takeovers, large firms acquired smaller ones. In the 1980s, junk bonds made it possible for "individuals, smaller entities, and investment banking fins" to take part.[93] In another contrast to past takeover waves (and ordinary M&A activity), these new players often intended to dismantle the acquired company rather than to assimilate it. Both factors-the increase in number of raiders, and the consequences of a successful takeover-have apparently increased managers' fears of takeovers markedly, and may also have depressed discretionary expenditures. Managers, feeling that an unwelcome takeover bid might come at any time, might take steps that approximate what they would do to defend against a real hostile takeover bid, with the same effects on spending for R&D and capital equipment. In mid-

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[90] Miller, op. cit., p. 18.

[91] Miller, op. cit., p. 31.

[92] Andrew Pollack, ''The Challenge of Keeping U.S. Technology At Home, " Z% New *York* Times, Dec. 10, 1989.

[93] John C. Coffee, Jr., "Shareholders Versus Managers: The Strain in the Corporate Web," in Coffee, et al., op. cit., p. 77.

1989, for example, Honeywell acted to discourage potential raiders by cutting out certain lines of business (reducing the breakup value of its assets), eliminating 4,000 jobs, repurchasing up to 10 million shares of its own stock, and increasing its annual dividend to shareholders by 31 percent.[94] There had been speculation that Honeywell might be a takeover target, but no actual bid.

Few companies make moves as dramatic as Honeywell's, but many members of corporate boards and senior managers report that hostile takeovers came to dominate corporate board meetings and decisionmaking to an unprecedented extent in the 1980s. The effect on overall business planning, almost certainly, was to increase the emphasis on distributing profits to shareholders in preference to reinvesting in the company.

Hostile takeover activity seems to be winding down, although not crashing; the number of deals completed in the first 9 months of 1989 was smaller, according to a preliminary estimate, than the number in the first 9 months of any of the preceding 3 years. The first three quarters of 1989 saw 2,298 completed acquisitions, compared to 2,790 in 1988, 2,851 in 1987, and 2,707 in 1986. However, the value of these deals in 1989 was $144 billion, just below the peak of $144.7 billion in 1988. The story is different for LBOs: there were slightly fewer completed in the first 9 months of 1989 (214) than in a similar period of 1988 (221), but the total value of those LBOs in 1989—$47 billion—was quite a bit higher than the previous high of $29.1 billion in 1988.[95] The numbers aren't the only story. There is a widespread perception that the market has grown pickier about the kind of deals that can be approved, and there has been a flight from junk bonds.[96] Acquisitions continue, but many believe that the wave of highly leveraged, bustup takeovers is on the wane. If this is true, it could provide time to examine how much of the negative effects of M&A is associated with this particular type of financial activity, and time for policymakers to evaluate how to tailor possible regulation to the real problems.

[94] Tony Kennedy, "Honeywell Acts Against Potential Raiders," *The Washington Post*, July 2571989,

[95] Judith H. Dobryzinski, "Deals, Yes. Maniac Deals, No," *Business Week*, Oct. 30, 1989.

[96] Christopher Farrell, with Leah J. Nathans, "The Bills Are Coming Due," *Business* Week, Oct. 30, 1989.

Chapter 4

Human Resources

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Manufacturing, like the rest of the economy, depends on the competence and ingenuity of workers, from the shopfloor to the executive suite. Sophisticated technology demands able people. Just as powerful machines can enhance the productive abilities of people, it takes well-trained people to get the best out of the machines.

The need for highly qualified people is not confined to an elite; the most productive technologies are those that exploit the talents of skilled people at all levels. This has been a cherished principle of American development, manifested in many ways. One is the commitment of the United States to universal education, probably the most important investment a nation makes in its people. During most of the 19th and 20th centuries, the United States enrolled a larger percentage of its population in school than did European countries.[1] Even now, although there are many serious problems with educational quality, American enrollment in primary and secondary education is among the highest in the world, and in postsecondary education the United States ranks much higher than any other nation. Fifty-seven percent of the relevant age group was enrolled in postsecondary education in the United States in 1987, compared to a weighted average of 38 percent in all other industrial market economies and lower averages for developing and less developed nations.[2] Nathan Rosenberg, describing the factors that led to the rapid rate of technological innovation in 19th-century America, writes,

> Not only did American society devote a large proportion of its resources to inventive activities; it is also apparent that the human resources of the country were well-equipped through formal education with the skills which might raise their productivity both as inventors and as successful borrowers and modifiers of technologies developed elsewhere.[3]

Kazuo Koike, writing about contemporary Japanese manufacturing and skills, puts it this way:

> The essence of the contribution of high morale is . . . in devising better work methods and production, which in turn demand technological knowledge by workers for maintenance . . . This kind of wide-ranging skill contains such knowledge and promotes the ability of workers to determine the causes of problems on the shopfloor and thus to contribute to productivity.[4]

Rosenberg and Koike both stress technological knowledge, and that is no accident. All fast developing and developed nations put heavy emphasis on education-both on high-quality education and on broad participation by all ranks of citizens. Among the developed countries, those best known for their heavy investments in education are either the richest (West Germany, Sweden) or the fastest growing (Japan).

Many leading-edge companies that have been most successful in applying advanced automation in manufacturing put a particularly high premium on the cognitive skills of workers. By replacing human labor in the more routine tasks, they create a greater concentration of tasks that require judgment and complex knowledge. The best preparation for a worklife that puts increasing emphasis on judgment and knowledge is a good education. Providing this preparation is now a grave challenge for America. It is the wellspring of competitive ability in Japan, several Asian developing nations, and many European nations.

EDUCATION: PREPARATION FOR COMPETITIVENESS

During much of the 20th century, the United States had the best educated work force in the world, and American manufacturing was the world's most dynamic and competitive. There is a causal connection between these two, although it is not perfect. At the turn of the century new forms of industrial and work organization, known now as Taylorism and

[1] Richard A. Easterlin, ''A Note on the Evidence of History,' *Education and Economic Development, C.* Arnold Anderson and Mary Jean Bowman (eds.) (Chicago, IL: Aldine Publishing Co., 1965). The figures are reproduced in Nathan Rosenberg, *Technology and American Economic Growth (New* York, NY: Harper & Row Publishers, 1972), p. 38.

[2] The World Bank, *World Development Report 1987 (New* York, NY: Oxford University Press, 1987), Pp. 262-263.

[3] Nathan Rosenberg, *Technology and American Economic Growth (New York, NY:* Harper& Row Publishers, 1972), p. 35.

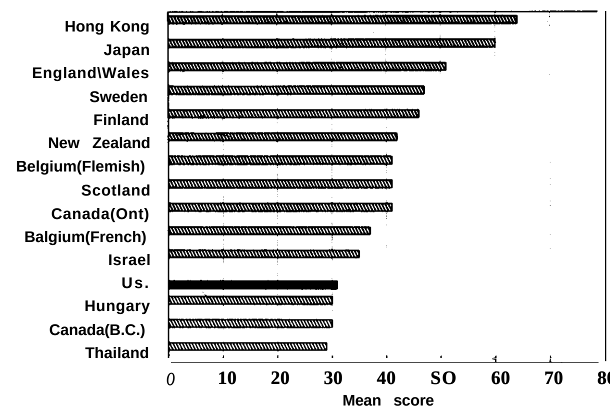
[4] Kazuo Koike, "Human Resource Development and Labor-Management Relations, " *The Political Economy of Japan, Volume 1: The Domestic Transformation,* Kozo Yamamura and Yasukichi Yasuba (eds.) (Stanford, CA: Stanford University Press, 1987), p. 327.

Fordism, tried to reduce jobs to their simplest components, which sometimes also had the effect of reducing the educational demands made on workers. However, many ordinary workers continued to bring ingenuity and creativity to their jobs, and it was this fact, as much as the efficiency of the assembly-line method, that impressed foreign observers about American manufacturing.[5] It is not a coincidence that America is now slipping on both counts, educational performance and manufacturing competitiveness.

American students perform poorly on standardized tests compared with their counterparts in many nations of Asia and Europe. Since the 1970s, they have compared unfavorably with their predecessors in American schools as well. In the mid-1980s American junior high school students ranked 10th in arithmetic, 12th in algebra, and 16th in geometry in a survey of mathematics competence in 20 countries.[6] Twelfth graders, compared with students from 14 other nations, ranked 12th in geometry and 14th in advanced algebra, according 1981-82 survey[7] (figures 4-1 and 4-2). American students scored below students in Canada (Ontario), Scotland, Finland, Sweden, Japan, New Zealand, Belgium, England and Wales, and Israel in functions and calculus. Of the students tested, only those in Hungary and the Canadian province of British Columbia performed worse. Moreover, the survey showed that the performance of American students had worsened in the past two decades. At the time of the frost international mathematics study in the early 1960s, the top 5 percent of American students were performing as well as the top 5 percent anywhere in the world. By the 1981-82 survey, the top 5 percent of American students had sunk to the bottom quarter of the scores of the top 5 percent in other nations.[8] The results are similarly dismal in science. Also, compared with students in many other developed nations, American students are less likely to learn foreign languages.

The deterioration in the performance of American students since the 1960s is just as disturbing as their poor showing in international comparisons. For many decades, American students scored higher year by year on standardized tests such as the Scholastic Aptitude Test and the Iowa Test of Educational Development. This progress was all the more impressive considering the fact that the American educational system was at the same time reaching more and more people. From 1890 to 1960, time spent in school, daily attendance, and the number of years of schooling completed all increased. For instance, the scores of 12th graders on the Iowa Test of Educational Development rose robustly between 1942 and the mid-1960s, with a dramatic spike in test scores after Sputnik's launch.[9] During about the same period (1941-68), high school graduation in Iowa, where the test was administered, increased from 65 to 88 percent of the relevant population. In the late 1960s, the gains stopped. Scores on many standardized tests began a decline that lasted for over a dozen years. The upturn in test scores in the early 1980s has only partially offset the decline. Young adults who entered the

Figure 4-l-Twelfth Grade Achievement Scores in Geometry



SOURCE: International Association for the Evaluation of Educational Achievement, *The Underachieving Curriculum: Assessing U.S. School Mathematics From an International Perspective* (Champaign, IL: Stipes Publishing Co., January 19S7).

[5]Jean-Jacques Servan-Schreiber, *The American Challenge (New* York, NY: Atheneum, 1969).

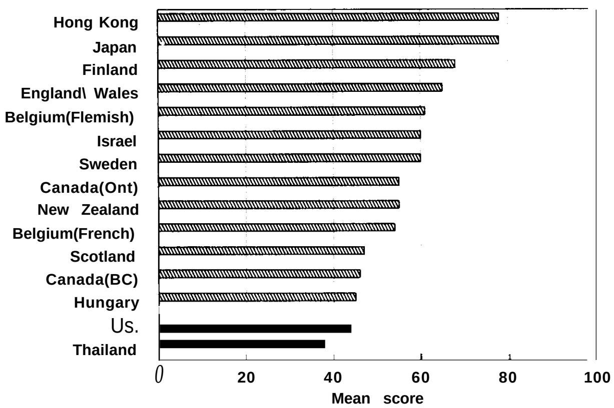
[6]Harold W, Stevenson, "America's Math Problems," *Educational Leadership,* October 1987; and International Association for the Evaluation of Educational Achievement, *The Underachieving Curriculum: Assessing U.S. School Mathematics From an International Perspective* (Champaign, IL: Stipes Publishing Co, January 1987).

[7]International Association for the Evaluation of Education Achievement, op. cit.

[8]Ellen Hoffman, "The 'Education Deficit', "*The National Journal,* Mar. 14, *1987.*

[9]John H. Bishop, "Is the Test Score Decline Responsible for the Productivity Growth Decline?" *The American Economic Review,* March 1989.

Figure 4-2-Twelfth Grade Achievement Scores in Advanced Algebra



SOURCE: International Association for the Evaluation of Educational Achievement, *The Underachieving Curriculum: Assessing U.S. School Mathematics From an International Perspective* (Champaign, IL: Stipes Publishing Co., January 19S7).

work force in the 1970s were less well prepared academically than their predecessors, an unprecedented occurrence in America.[10]

THE MANUFACTURING CONNECTION

The strength of a nation's scientific and engineering work force is connected to manufacturing innovation and competitiveness in immediate and obvious ways. The academic accomplishments of shopfloor workers are not so obviously related to competitiveness. When we consider the nature of much factory work—short-cycle repetitive tasks—the relevance of performance in science and mathematics may seem slight.

Yet manufacturing work is changing with advances in technology, and the changes often demand skills that are more in line with academic competence than those required in earlier generations of mass-production factory work. Automated production makes each worker responsible for a larger share of the production process, and creates a greater need for each worker in the system to understand other parts of the system. Emphasis on product quality, often formalized into statistical process control (SPC) procedures, requires workers to have basic skills in reading and math. For example, at a Fujitsu Microelectronics semiconductor plant in San Diego, California, most production jobs require good arithmetic skills, including proficiency with fractions and decimals, to cope with the demands of SPC.[11]

Automated production also requires sound judgment and skill in problem solving. An account of work in a silicon wafer plant in North Carolina states,

> At DNS, the silicon log in its raw state is worth between $2,000 and $5,000. This fact and the cost and expense of the machines employed in sawing make "down time" far more acceptable than scrap. Although the only direct control an operator may have over his or her process is an on/off switch, timely and judicious use of that switch is becoming a high skill.[12]

Programmable automation and/or flexible manufacturing systems require multiple skills, many of them new for production workers. Programmable equipment enables one machine or group of machines to make a much wider range of parts or products than dedicated machines. In the past, workers could learn in a few days or weeks, by watching and working with an experienced worker, how to operate a particular machine. Now, workers must identify more closely with products than with processes or machines, and they are less likely to be buffered from other machines and workers by large stocks of parts and loose schedules. As a result, they must be more familiar with the whole production process and able to operate multifunctional machines. In such a system, operators can no longer rely on learning by example, but instead must be able to read and understand manuals and specifications.[13]

These skills are hard to translate into grade-level equivalents, but training directors of firms that have confronted difficulties with problem-solving ability recognize that a basic proficiency in reading and mathematics is both a good foundation for and an indicator of problem-solving ability. Motorola, for

[10] Ibid., p. 193.

[11] Paul V. Delker, "Worker Training: A Study of Nine Companies," contract report to OTA, September 1988.

[12] Ibid.

[13] Larry Hirschhorn, "Training and Technology in Context: A Study of Four Companies," contractor report to OTA, September 1987.

example, determined that workers in its Factories of the Future-fully automated semiconductor production facilities-needed at least sixth grade math and seventh grade reading to cope with demands for mastering different jobs in a rotation system, assuming responsibility for quality control, and participating in problem-solving work teams.

While these requirements are modest, many workers do not possess them. Of a group of 278 Motorola production workers who volunteered for testing, 85 percent were in need of some remedial instruction in order to meet the standard of sixth grade math and seventh grade reading. Most of the people who failed to meet the standard in both reading and math were workers whose native language was not English. Fujitsu's San Diego plant, producing integrated circuits and semiconductors, had the same problem: lack of the basic skills needed for effective participation in quality circles (work groups focused on problem solving). Here, too, the trouble stemmed largely from the fact that many employees, including the Japanese plant managers, were not native English speakers.

This does not mean that basic skills deficiencies in American manufacturing are confined to immigrant populations. Many companies have found that poor basic skills among native workers limit their ability to adopt new technologies. Their experiences are confirmed by results of the National Assessment of Educational Progress' survey of literacy proficiency among young adults aged 21 to 25. Although the NAEP findings show that nearly all young adults are literate in a rudimentary sense, 20 percent of young American adults read no better than a typical eighth grader and 6 percent do no better than the average fourth grader.[14] Moreover, very few young adults were proficient in tasks requiring even a moderate level of complexity. For example, only 9.5 percent of the group, given typical grocery store price information on a unit-cost basis, could select the least expensive of two brands of peanut butter.[15] While it is not focused on the basic skills requirements for work, the NAEP study makes clear that large numbers of young American workers do not come into the workplace with the basic academic skills that employers could expect from their years of formal schooling. Such problems are not confined to new entrants, products of an educational system with slipping standards. They are found also among midcareer and older workers, people whose basic proficiencies were perhaps not strong to begin with, or whose skills have rusted with little use.

With the quality of American academic achievement only now showing signs of rebounding, the prospect is that things will get worse, not better. The growth rate of the labor force is slowing, and a high proportion of the new entrants over the next decade will be from demographic groups (blacks, Hispanics, and immigrants) that traditionally have been educationally disadvantaged. Faced with a declining pool of qualified applicants, employers may not be able to be as selective in their hiring as in the past. Even if educational quality rebounds strongly in the primary and secondary schools, the generation of people that entered the work force in the 1970s, and into the early 1980s, could still depress overall American productivity growth well into the next century, unless employers and public programs take strong measures to help large numbers of workers learn to read, calculate, and communicate better.[16] Well-designed programs can help workers with rusty basic skills improve enough to handle such challenging tasks as statistical quality control and daily maintenance of sophisticated equipment.[17]

In some countries-West Germany is a prime example-a nationwide system for teaching young people technical skills adds a further advantage to that provided by a sound basic education. About two-thirds of Germany's young people go through a 3-year work apprenticeship after finishing compulsory academic schooling at age 16. The vocational training combines classroom studies 1 day a week with organized work the other 4 days, either in a workshop or a regular workplace. To qualify as a craftsman, the trainee has to pass practical tests and a 4-hour written exam. There is evidence that this century-old system (it started with Bismarck) pays off handsomely in productivity, quality, and flexibility in manufacturing.

[14] Irwin S. Kirsch and Ann Jungeblut, Literacy: *Profiles of America's Young Adults* (Princeton, NJ: Educational Testing Service, 1986), p. 40.

[15] Ibid., p. 34.

[16] OTA is conducting an assessment of 'Worker Training: Implications for U.S. Competitiveness,'' to be completed in 1990. Preliminary results of this assessment indicate that the lack of basic skills among manufacturing workers is a solvable problem, but does require effort and expense.

[17] Delker, op. cit., passim.

A mid- 1980s series of studies comparing matched British and German manufacturing plants-in metal-working, kitchen cabinet manufacture, and garment making-found that the German plants had labor productivity advantages of 60 to 130 percent.[18] In each case, the studies concluded that a major reason for the German advantage was the country's better trained, more highly skilled shopfloor workers. (Technical training of foremen and higher managers was found to be at least as important, in some cases more so.) For example, in the kitchen cabinet plants, nine-tenths of all the German workers on the shopfloor had had 3-year apprenticeships followed by qualifying examinations. At best, one-tenth of production workers in the British plants were so qualified, and several British plants had no workers with similar training. One result: the German workers were adept at using computerized wood-working machinery and a linked system for feeding, unloading, and stacking materials. Fully linked machine lines were hardly to be found in the British plants, one main reason being fear that one of the linked machines would "go wrong" and stop the whole line.

Breakdowns of all kinds of machinery were far more frequent in the British plants-another sign of insufficient worker training. The German operatives routinely clean and maintain their machines, whereas this kind of planned maintenance is virtually unknown in the British plants, according to the study .19 Similarly, in metalworking, breakdowns of machinery-especially of advanced computer, numerically controlled machinery-were a serious, continuing problem in British plants, while the German plants reported only startup problems, never continuous longstanding difficulties.[20]

Apprenticeship training was also credited with helping German shopfloor workers adapt easily to changing requirements. This adaptability is essential to the strategy of the German clothing industry, which concentrates on short runs of high-priced quality products and pays relatively high wages—at least 50 percent higher than wages in the British industry. In the German plants visited for the study, 80 percent of sewing machine operators had completed a full 2-year apprenticeship; no British firm had a single machinist with equivalent training.[21] The German machinists needed only 2 days to reach top-speed production on a new style, and most were able to work on new operations directly from technical sketches. The British machinists typically took several weeks to master a new style, and few could work from technical sketches. Also, quality was apparently much better in the German plants, since the number of quality controllers (passers) was only 1 for 23 machinists, compared to 1 for 7 in Britain. Undoing of faulty work was often observed in the British plants visited, but not once in the German.

It is not the apprenticeship training alone that serves German manufacturing so well. The level of math competence of the average school leaver (age 15 to 16) is substantially higher in Germany than in Britain, and the relative advantage is especially marked for the less academically ambitious students (those most likely to take up operative work) .22 Nor is a public system of vocational training the only way to give production workers the technical skills they need for advanced manufacturing. In Japan, for example, immensely successful international firms such as Toyota or Mitsubishi hire high-school graduates with no special technical training and give them company training. Japan's publicly funded, vocational training institutes typically serve the needs of smaller companies. Many American managers also think they can train production workers adequately, if the workers know how to read, figure, and communicate adequately and have good work habits. The sine qua non is good basic skills.

18Productivity was figured on the basis of physical units of production for similar items. The studies were: A. Daly, D.M.W.N. Hitchens, and K. Wagner, "Productivity, Machinery and Skills in a Sample of British and German Manufacturing Plants,' *National Institute Economic Review, February 1985;* Hilary Steedman and Karin Wagner, "A Second Look at Roductivity, Machinery and Skills in Britain and Germany,' *National Institute Economic Review,* November 1987; Hilary Steedman and Karin Wagner, "Productivity, Machinery and Skills: Clothing Manufacture in Britain and Germany, " *National Institute Economic Review, May 1989.* See *also these* papers by S.J. Rais and Karin Wagner in the National institute *Economic Review* "Some Practical Aspects of Human Capital Investment: Training Standards in Five Occupations in Britain and Germany, '' August 1983; ' 'Schooling Standards in England and Germany: Some Summary Comparisons Bearing on Economic Performance,' May 1985; "Productivity and Management: The Training of Foremen in Britain and Germany," February 1988.

19Steeman and Wagner (1987), op. cit., p. 89.

20Daly et al., op. cit., p. 55.

21Steeman and Wagner (1989), op. cit., p. 49.

22Prais and Wagner (1985) and (1988), op. cit.

THE TECHNICAL AND ENGINEERING WORK FORCE

Although good basic skills throughout the work force are fundamental for good manufacturing performance, the defects of ordinary American education and the lack of a robust vocational training system may be more damaging to the nation's technical operatives than to its blue collar workers. Assuming that production workers are competent in reading and simple math, or need no more than brush-up courses, they can be trained for many shopfloor jobs in a matter of weeks. Training of technicians-those who do nonroutine maintenance, programming, and repair of equipment—takes months to years, on top of decent reading and math skills.

One conclusion of the comparative studies of German and British manufacturing plants was that the superior training of foremen in Germany was a key advantage to manufacturers. The German foreman combines technical and managerial skills. He or she supervises workers in the routine care and maintenance of machinery, adapts standard machines to specialized needs, and works with suppliers in developing new machines. The foreman is also responsible for scheduling work (often using computers for the purpose) and ensuring delivery on time.

Most foremen are qualified as *Meister*, or advanced mechanic. Candidates for the *Meister* qualification must first have at least 3 years' full-time work experience following their apprenticeship and qualification as craftsman. Then they take a prescribed set of courses in technical topics, business organization, and training responsibilities, either part-time over 2 or 3 years or full-time for about 9 months. The courses are free but candidates take them on their own time. The written examinations at the end of the course typically take about 17 hours, spread over 3 days. Advanced mechanics in textiles, for example, must pass an exam covering the following subjects:

1. origins and qualities of raw materials and textile products;
2. yarn and thread production;
3. yarn and thread construction;
4. the organizational structure of the firm;
5. the rights and duties of workers;
6. safety rules and first aid;
7. adjustment and operation of fiber preparation machines;
8. adjustment and operation of spinning machines;
9. ability to determine the quality of yarns and threads;
10. maintenance of tools, machines, and equipment;
11. machine parts;
12. electronics;
13. fundamental metalworking; and
14. installation and repair of machines.[23]

This rigorous training and accreditation system for technicians or foremen is routine in Germany, but practically unknown in America. Yet, particularly in automated manufacturing systems, the need is increasing for numbers of people who have the kind of broad mastery described above, people who understand the entire production system and keep it running. Remedying a shortage of these skills is made considerably more difficult when the work force is populated by men and women whose basic educational preparation is poor.

The Engineering and Scientific Work Force

The problem of poor preparation in public schools may turn out to be more acute in the engineering and scientific work force. It takes at least 4 years to produce an engineer, assuming the student has had a solid secondary education. It takes longer to produce most scientists. If because of inadequate basic education the United States cannot keep a healthy flow of scientists into research and development and engineers into R&D and industry, American manufacturing industries will find it increasingly difficult to keep up with, not to mention outperform, industries in other nations.

Several trends are worrisome. First is the number of scientists and engineers in the work force, particularly those employed by industry. The proportion of scientists and engineers in America's work force has remained fairly constant through the last two decades, while in Japan it has risen steadily. Now, Japan has about as many scientists and engineers employed per thousand workers as Amer-

[23] Wayne Brooke Nelson, *Improving Competitiveness in Mature Industries: Lessons From the West German Textile Industry*, Master's Thesis, Massachusetts Institute of Technology, October 1987.

ica, but will soon have significantly more, unless the trends change. Second, it will be hard to spur growth in the number of engineering graduates in America because of three impediments: the poor performance of average American students in science and mathematics in secondary schools; the increasing proportion in the population of America's young people of minorities, who have traditionally done poorly in science and math; and the increased efforts by foreign governments to attract home their own nationals who are graduates of American engineering and science programs.

There are also some more specific problems. Improving productivity and quality in manufacturing means attracting more engineers to manufacturing, and not just to the lucrative electronics industries. Manufacturing engineering has enjoyed much lower status than other engineering specialties, and there are few signs of change. Also, many engineers and scientists are diverted from civilian industries to work on defense technology; it is estimated that 20 percent of U.S. engineers are in defense work.[24] The debate over how much of the engineering and scientific knowledge generated by the DoD spills over into civilian sectors will not be resolved here. However, defense work provides few benefits to most manufacturing industries (aerospace and, to a lesser extent, electronics are where DoD technology has most of its civilian application).

Finally, there are qualitative differences in how Japanese and American engineers spend their days. Japanese companies are structured to do what they are renowned for: make things better, and faster, and less expensively. Accordingly, their use of engineers is well adapted to continual incremental improvement of products and especially manufacturing process. They are not particularly known for coming up with a steady stream of larger technological breakthroughs. American companies, on the other hand, are better known for the stimulation of engineers' creative abilities, but are less effective in day-to-day improvement or in meshing engineers' design with shopfloor production. While both countries are making efforts to reproduce each other's strengths, there is little doubt that the Japanese system has served manufacturing competitiveness better than the American system has in the past few decades.

Numbers and Distribution of Scientists and Engineers

The concentration of scientists and engineers in a nation's work force says much about its capacity for innovation and improved productivity.

Among five industrialized nations-France, West Germany, Japan, the United Kingdom, and the United States—the United States ranks first in the number of scientists and engineers per thousand people in the work force by a small margin (figure 4-3). When it comes to the engineering work force, the United States, with 175 engineers per 10,000 workers in 1984, has a slightly lower concentration than Japan (187 per 10,000 in 1985) or West Germany (194 per 10,000 in 1985), and a higher concentration than the United Kingdom (144 per 10,000 in 1981) or France (105 per 10,000 in 1982).[25]

The number of people entering or graduating from science and engineering programs in this country has responded readily to market forces in the past. The boom in industrial demand for computer scientists, for example, has made computer science the fastest growing field of science at all degree levels.[26] Patricia Flynn, analyzing the shift in industrial composition of the Lowell, Massachusetts area between 1970 and 1982, found that:

> The occupational education network was highly responsive to overall occupational trends in the area and to the particular needs of the high-technology industries. Three-quarters of the occupational education programs, accounting for 85 percent of all of the trained graduates, were "on target" or "reasonably aligned" with occupational employment changes in the Lowell area during the 1970s.[27]

Specifically, Flynn showed how local educational institutions shifted to meet the change in local

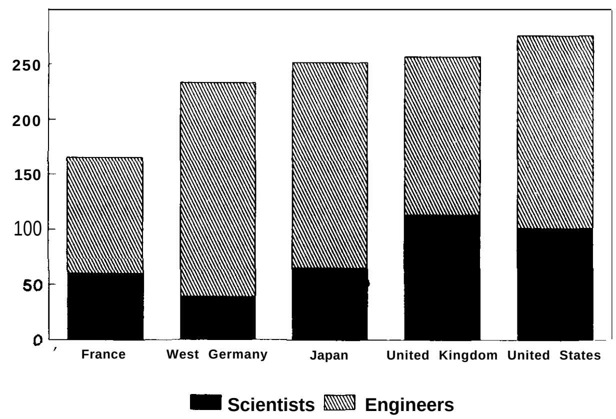
[24] National Academy of Sciences, *The Impact of Defense Spending on Nondefense Engineering Labor Markets (Washington, DC:* National Academy *Press, 1986),* p. *74.*

[25] National Science Foundation, National Science Board, *Science and Engineering indicators-1987,* NSB 87-1 (Washington, DC: U.S. Government Printing Office, Nov. 30, 1987), p. 226, appendix table 3-15.

[26] U.S. Congress, Office of Technology Assessment, *Educating Scientists and Engineers: Grade School to Grad School, OTA-SET-377* (Washington, *DC:* U.S. Government Printing Office, June 1988).

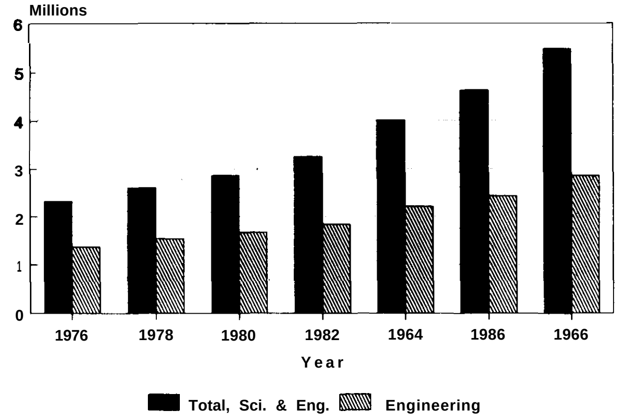
[27] Patricia M. Flynn, Facilitating *Technological Change: The Human Resource Challenge* (Cambridge, MA: Ballinger Publishing Co., 1988), p. 101.

Figure 4-3-Scientists and Engineers per 10,000 Labor Force



SOURCE: National Science Foundation, National Science Board, *Science and Engineering Indicators—1987*, *NSB87-1* (Washington, DC: U.S. Government Printing Office, Nov. 30, 1987), appendix table 3-15.

Figure M-Employment of Scientists and Engineers



*Estimate.

SOURCE: National Science Foundation, "U.S. Scientists and Engineers: 1988," NSF 88-322, 1988, table 1.

employment patterns and industrial growth. Traditional manufacturing in Lowell was marked by declining average annual employment of 4.0 percent in textiles, 4.9 percent in apparel, and 8.4 percent in leather between 1976 and 1982. At the same time, employment in high-technology sectors took off: annual employment growth in nonelectrical machinery (including computers) was 43.3 percent; in instruments, 23.6 percent; in transportation equipment (mostly aerospace), 7.2 percent; and in electrical and electronic equipment, 7.2 percent.[28] Lowell's educational institutions responded, and the numbers of graduates from high-technology programs grew more than twice as rapidly as the number of graduates from all the other occupational programs.

More generally, engineers and scientists seem to be in adequate supply in the United States-so far. During the past decade there has been healthy growth in the nation's scientific and engineering work force (figure 4-4). Both market forces and government policies have proven effective at drawing people into engineering and science schools, and at attracting people who are qualified to work in engineering from other fields. Federal funding of graduate fellowships has encouraged enrollment in science and engineering and caused some students to shift their postdoctoral plans.[29] Federal science and technology initiatives, such as NASA programs and those at the National Institutes of Health, have also helped to create a healthy job market for graduates. Finally, the boom in microelectronics and computer industries in the 1970s and 1980s also drew many people into science and engineering curricula, especially electronic engineering specialties and computer science. Between 1976 and 1986, for instance, the work force increased just over 2 percent per year, while the number of computer scientists increased nearly 17 percent per year, and the number of electrical engineers increased 7 percent per year (figure 4-5).[30]

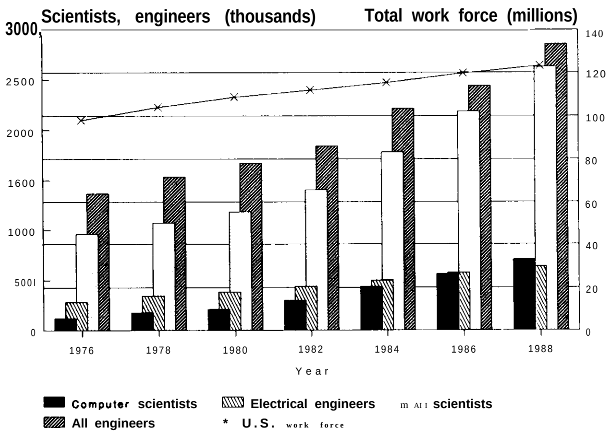
But the trend is a bit bleaker. In the past, engineers and scientists were typically white males. They now make up a shrinking proportion of the pre-college population, which is itself growing smaller. The greatest growth is in the Hispanic population, with a more slowly rising proportion of black people. By the year 2000, 25 percent of the college age population will be black or Hispanic. These two groups, which are more likely to live in poverty, perform less well in school and have had higher dropout rates than white or Asian ethnic groups. It will take greater efforts to prepare and recruit them

[28]Ibid., p. 81.

[29]Ibid., p. 17.

[30]U.S. Department of Labor, *Employment and Earnings*, any issue; and National Science Foundation, *U.S. Scientists and Engineers: 1986*, NSF 87-322 (Washington, DC: U.S. Government Printing Office, 1987).

Figure 4-5-Trends in Science and Engineering Labor, 1976-88



● Estimates, except for total work force.

SOURCES: National Science Foundation, "U.S. Scientists and Engineers: 1988," NSF 88-322, 1988, table 1; and U.S. Department of Labor, Bureau of Labor Statistics, "Employment and Earnings," vol. 36, No. 12, December 1989, table AI.

into the ranks of scientists and engineers. If fewer young people enter engineering and science programs, salaries will be bid up, and employers might face rising costs of securing technical talent. Even with manufacturing employment shrinking, the demand for engineers and scientists might not decline or might even rise, as it takes increasing numbers of scientists and engineers to keep manufacturing competitive. If salaries rise, it will be more expensive to solve technical problems in manufacturing, develop technology, run and adapt equipment. While large companies and high-technology companies will continue to employ engineers and scientists, more small companies will find it hard to afford even one engineer.

To guarantee a steady stream of qualified entrants into college engineering programs, many actions will be needed. One is investment in primary and secondary school programs designed to improve performance in math and science. Actions to attract and retain larger numbers of students into engineering and science would require a substantial commitment of resources, and take many years to yield significant results .31

In the meantime, the Japanese system is already primed to prepare, recruit, and educate engineers. Currently, the concentration of engineers in the Japanese work force is only modestly higher than in the U.S. work force (187 per 10,000 workers in Japan v. 175 per 10,000 in the United States) and their concentration of scientists is much lower (65 per 10,000 in Japan, compared with 101 per 10,000 in the United States) .32 But the educational system of Japan is effectively geared to produce new engineers of a high caliber, while the American system needs substantial improvement before the feed rate into engineering curricula can be stepped up, or even maintained. Over 4 percent of 22-year-old university graduates in Japan hold degrees in engineering, compared with less than 2 percent of 22-year-old college graduates in America. While the absolute numbers are roughly comparable-71,400 new engineering graduates in Japan in 1985, and 77,900 in America-the emphasis of the Japanese system is clear, considering that Japan's population and GNP are about half that of the United States.

Despite its current favorable position, Japan faces its share of problems in engineering. Maintaining strength in manufacturing may prove a bit more difficult than Japan's impressive record would indicate. *Endaka,* or high yen, squeezed Japanese manufacturing, and while industry responded admirably to the challenge, the constraints of being a high-cost nation are beginning to have effects that concern many Japanese observers. Specifically, with the pressure to increase productivity and hold down wages, many newly graduated engineers are opting for careers that offer greater financial rewards than manufacturing. Currently, beginning engineers in manufacturing earn only a bit more than workers with no more than a high school education. In 1987-88, average earnings for male systems engineers 20 to 24 years old were 150,000 yen per month ($1,071 at 140 yen to the dollar); their earnings peaked at 401,400 yen per month ($2,867) for 45 to 49 year-olds (figure 4-6). Prospects for graduating engineers are much more lucrative in Japanese finance, at least for now. The salary of a midcareer (35-year-old) employee in a Japanese bank is the equivalent of $70,000 to $80,000 per year, about

[31] See U.S. Congress, Office of Technology Assessment, *Educating Scientists and Engineers: Grade School to Grad School,* OTA-SET-377 (Washington, DC: U.S. Government Printing Office, June 1988) for a detailed discussion of these policy options.

[32] National Science Foundation, National Science Board, *Science and Engineering indicators-1987,* op. *cit.*

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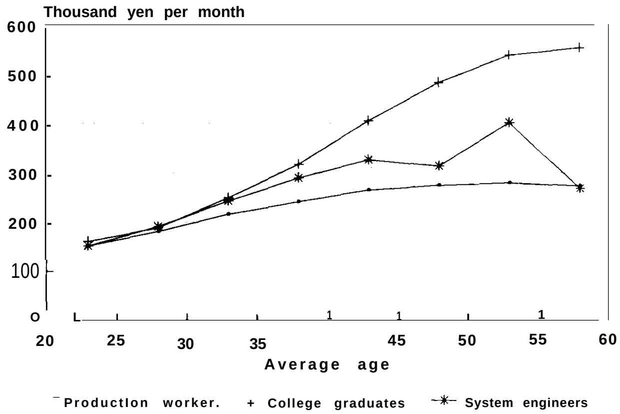
Figure 4-8-Salaries of Engineers and Laborers of Large Establishment= in Japan, 1987-88



SOURCE: Japan Productivity Center, *Practical Handbook of Productivity and Labour Statisitcs '87-'88* (Tokyo, Japan: Japan Productivity Center, 1988), tables 11 and 13.

double the salary of a midcareer manufacturing professional.[33] Little wonder, then, that new engineering graduates should opt for other sectors as they leave school.

The salary differentials-and possibly, the sinking prestige of a career in manufacturing compared with other opportunities-are taking a toll. While 60 percent of graduates from all Japan's engineering universities still entering manufacturing (roughly the same proportion as in the past), the sector is losing its appeal for engineers graduating from the three most prestigious universities (Tokyo University, Tokyo Institute of Technology, and Waseda University). About 80 percent of the engineers from those institutions chose to enter manufacturing in 1982. The proportion has been declining ever since, dropping under 60 percent in 1988. Many of these graduating engineers are being lured into banks and securities companies, where the jobs pay more and the opportunities are regarded as more exciting. A recent survey of electrical engineers showed that younger engineers feel more strongly than other young workers in Japan that they are unable to fully use their talents, and that they cannot do what they're interested in. In addition, like other young workers in Japan, they feel underpaid.[34]

Thus, Japan is not free of difficulties in attracting engineers into manufacturing. However, the superior educational preparation of Japanese students may make Japan's problems easier to solve than ours. Japan's large pool of people who are able to enter science or engineering could be an important safety valve as it enters its own version of uncharted waters. Just as the United States is trying to cope with international competition on an unaccustomed scale, Japan is trying to improve its ability to generate breakthrough advances in science and technology while maintaining its strength in manufacturing process. The new emphasis on innovation probably means that Japan will need many more scientists than it has, and that it will have to spend more on basic research both in industry and in universities-which, compared to American universities, contribute much less to the national stream of technological development and innovation. In addition, some departures from the traditional, seniority-based career paths of Japanese scientists and engineers may be needed.

So far, it is hard to make any case that America doesn't have enough engineers, particularly in manufacturing. There are nearly as many engineers in manufacturing in the United States as in Japan and Germany, and more scientists; there is no artificially created scarcity. The number of people entering or graduating from science and engineering programs seems to respond readily to market forces or at least has done so in the past. The boom in industrial demand for computer scientists, for example, has made computer science the fastest growing field of science at all degree levels. The principal worry for the near future, so far as supply is concerned, is the trend in demographics.

The Functions of Engineers in Japan and America

Japanese and German manufacturing, both renowned for their attention to precision and quality, employ about the same number of engineers per worker as American manufacturing, which no longer has the same reputation. Obviously, it is not just the number of engineers in manufacturing that counts but also how they spend their time.

The Japanese have consistently surpassed their U.S. competitors in manufacturing things reliably, with high precision, and at reasonable costs. In other words, they have devoted more effort than Ameri-

[33]Bob Johnstone, "A Technical Hitch," *Far Eastern Economic Review,* Feb. 16, 1989, p. 49.

[34]Ikutaro Kojima, Yoshio Nishimura, and Toru Suzuki, "The Changing Role of Japan' s EEs," *Electronic Engineering Times, Dec. 5, 1989.*

cans to ironing out the large and small problems of manufacturing. In comparison, American firms have tended to put more emphasis on innovation. Job assignments differ for engineers in America and Japan, as does the relation between design and production engineers.

The careers of Japanese and American engineers in industry differ starting from the time they complete their schooling and join a manufacturing firm. In sharp contrast to American engineers, Japanese engineers are likely to stay with the firm until retirement, and to progress along a fairly predictable path through the hierarchy of the company. Few leave firms and move to another in midcareer. They are more likely to be transferred by their company to an area outside their specialty. The objective is to broaden their job skills and broaden their knowledge of other functions. American engineers are likely to become managers earlier than their Japanese counterparts, and to broaden their knowledge by transferring between companies rather than within them.[35]

About one-third of American engineers work in research and development (940,000 out of a total of 2.8 million, as of 1988).[36] In addition, some 275,000 engineers are involved in the management of R&D. Only about 17 percent of American engineers (495,000 people) work on the shopfloor, in production and inspection.[37] The same pattern, in a more extreme form, prevails in West Germany, where 50 percent of engineers work in R&D, and only 12 percent in manufacturing production and repair.[38] While comparable data are not available for Japan, there are strong indications that the Japanese firm deploys its engineers differently. Japanese engineers are much more likely than their American counterparts to have at least one assignment in a new area to broaden their skills: 62 percent of Japanese engineers report at least one job rotation assignment, compared with only 35 percent of American engineers. Thirty-five percent of Japanese engineers were assigned at some point to production, compared with only 14 percent of American engineers, and 50 percent of Japanese engineers have served one outside assignment in research, design, and development activities, compared with only 14 percent of American engineers.[39]

These standard job rotations afford Japanese engineers the opportunity to acquire a firsthand knowledge of and sensitivity to the problems and constraints of manufacturing. Most observers agree that this understanding explains much of the ability of Japanese manufacturers to bridge design and engineering functions effectively. American engineers, who rotate functions less frequently but change firms far more often, may acquire some understanding of both manufacturing and design, but the record of Japanese and American manufacturing suggests that it is relatively unusual. In Japan, the transfer of research or development to manufacturing is accomplished by transferring people directly, while in the United States one manager is more commonly assigned the responsibility for transferring the knowledge from design teams to production people.[40] The fact that American firms generally make much less effort than Japanese to smooth the differences between product and manufacturing process design and startup shows up in designs that are harder to manufacture, longer startup times, and lower process efficiency.

Japanese engineers are more likely than their American counterparts to take responsibility for making sure their designs are manufacturable, a fact supported by considerable anecdotal evidence. A good example—also typical of the kinds of stories told about interactions of design and manufacturing engineers--comes from an engineer now at Sematech, the U.S. semiconductor manufacturing development consortium. The engineer once worked for a major U.S. semiconductor manufacturer producing 1 megabit DRAMs, and then for Siemens on the Mega Project, the European program to design and manufacture 1M and 4M DRAMs. He recounted the tale of the U.S. fro's unsuccessful attempts to manufacture 1M DRAMs efficiently (e.g., with high yields and low cost). After developing the process

35See Leonard H. Lynn, Henry R. Piehler, and W. Paul Zahray. "Engineering Careers in Japan and the United States: Some Early Findings From an Empirical Study," mimeo, n.d.; and D. Eleanor Westney and Kiyonori Sakakibara, "Designing the Designers," *Technology Review*, April 1986.

36National Science Foundation, *U.S. Scientists and Engineers: 1988*, NSF 88-322, 1988.

37Ibid.

38National Science Foundation, *Scientists and Engineers in Industrialized Countries* (Washington, DC: CIR Staff Paper, November 1986), p. 25.

39Lynn, et al., op. cit. These percentages describe only the job *rotation* experiences of engineers, not their current positions.

40Westney and Sakakibara, op. cit., p. 28.

and prototypes in the laboratory, the company turned the design over to the factory, where manufacturing engineers were unable to get chip yields up to competitive levels. The manufacturing engineers protested that the process had no margin for error, but they did not themselves have the resources or knowledge to do paper analysis and make improvements. The designers, on the other hand, insisted that they had developed a robust and manufacturable process, and shied away from correcting the problems. At Toshiba, where the 1M DRAM process quickly resulted in very high yields, the engineers and scientists who developed the 1M DRAM process and presented the results to the scientific community[41] were also responsible for yield improvement activities.[42]

Case studies also indicate that Japanese firms often have more engineers on the shopfloor than do U.S. firms. In a study of flexible manufacturing systems (FMSs) in the United States and Japan, Jaikumar concluded that the Japanese companies used the systems far more effectively than the American fins. They got their systems up and running in much shorter time and made many more kinds of parts. Further, their machines had far less down time. Much of the difference arose from the ways in which the two countries used their engineers. U.S. managers treated their FMSs inflexibly, like hard-wired equipment, while the Japanese continued to tinker and make incremental improvements.

The adjustments needed to exploit the flexibility of programmable machinery can generally only be done by engineers. In Japanese firms using FMSs, 40 percent of the staff were college-educated engineers, and all the workers were specially trained in the use of computer numerically controlled (CNC) machines. In the U.S. companies, only 8 percent of the workers operating the FMSs were engineers, and fewer than 25 percent of all workers had been trained on CNC machines. In the U.S. firms, the project team of engineers and software specialists who designed the system disbanded and left after they had it debugged and running. In Japan, the engineers who designed the system remained to operate it, making continual programming changes, writing new programs, and staying with it until they achieved untended operation at least 90 percent of the time. In a fully automated FMS metal-cutting operation, Jaikumar found, engineers would outnumber production workers three to one, but the system would require less than half the number of engineers needed in a conventional U.S. system.[43]

[41] Syuso Fujii et al., "A 50 [mu]A Standby 1Mx1/256Kx4 SMOS DRAM With High Speed Sense Amplifier," *IEEE J. Solid-State Circuits,* vol. *SC 21,* October 1986, pp. 643-647.

[42] Personal communication, D. Robyn, S. Baldwin, and A. Buyrn of OTA with Peter Nunan, Sematech, May 10-12, 1989.

[43] Ramchandran Jaikumar, "Postindustrial Manufacturing," *Harvard Business Review,* November-December 1986.

Chapter 5

Links Between Firms and Industries

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Chapter 5
Links Between Firms and Industries

Industries do not standalone. They are linked with suppliers of machinery and materials in one direction and with a chain of customers in the other. How a firm or an industry handles these relations has a good deal to do with its competitive performance. In all kinds of manufacturing industries, close links and stable relations between suppliers and purchasers seem to be important factors in boosting overall performance, including productivity, quality, and innovation.

U.S. industries, on the whole, have not been strong on collaborative vertical links. The traditional relation between supplier and customer has instead been distant, even adversarial, and based mainly on price.[1] But there are signs of a trend toward more collaboration. U.S. auto companies are trying to form closer, longer-term relations with parts suppliers. Sematech, the industry-government consortium dedicated to improving manufacturing technology in semiconductors, began by strengthening ties between chipmakers and producers of the materials and equipment used to make chips. Textile companies are forging stronger links backward to fiber suppliers, forward to apparel makers, and beyond to retailers. Individual firms that have made a comeback against foreign competition use close supplier links as part of their strategy, a leading example being Xerox.

The trend toward closer links is certainly not universal. Nor is it likely that American manufacturers will ever replicate the distinctively Japanese style of close, mutually obligating bonds between parent and subsidiary companies (even in Japan the bonds are weakening somewhat). But the advantages of collaborative links, throughout an industry complex and between related industries, are increasingly appreciated.

LINKS BETWEEN MAJOR MANUFACTURERS AND SUPPLIERS

Traditionally, U.S. manufacturers have either supplied their own materials and parts (in vertically integrated companies) or, when dealing with outside suppliers, have kept them at arm's length. A common strategy has been to pit one supplier against the other and drive the hardest possible bargain on price. In offering their own goods to the next producer down the chain, the main selling point has also been price, with quality, service, and responsiveness to customers' needs taking a lesser place. This approach is not confined to the United States, but is typical in many market-oriented industrial countries.

A different pattern is common in Japan. In the world-class industries that have led Japan's strong trade performance, manufacturers generally maintain long-term, collaborative relations with their outside suppliers. They are demanding on price and equally demanding on quality and just-in-time delivery, but they also give their suppliers technical help--occasionally financial help as well—in meeting these demands. Suppliers who show they are able to satisfy the manufacturer's demands can be fairly confident of keeping the business, rather than losing out to a price-cutting competitor. This pattern is part of the overall Japanese approach of careful attention to all aspects of manufacturing, including the quality of components and supplies.

The manufacture of motor vehicles offers an exceptionally clear picture of these alternate ways of handling links with suppliers. Organization of supply is a central feature of the auto industry, since the average car or truck contains some 15,000 parts. Historically, U.S. automakers have chosen one of the two opposite approaches: either vertical integration (as practiced by General Motors, which is 70

[1] The pattern is not invariable. For example, major airlines have long had close, cooperative ties with the manufacturers of aircraft, with airline engineers taking a leading part in design and purchase decisions. However, with deregulation of the industry, the ties are loosening; airlines are cutting their engineering staffs and making purchase decisions more strictly on the basis of price. See the case study of the commercial aircraft industry in Michael L. Dertouzos, Richard K. Lester, Robert M. Solow, and the MIT Commission on Productivity, Made *in America: Regaining the Competitive Edge* (Cambridge, MA: The MIT Press, 1989).

percent integrated), or arm's-length purchase from suppliers bidding against each other (Chrysler, 25 percent integrated). Vertical integration is supposed to have the advantage of lowering barriers between supplier and main company (reducing transaction costs)--e.g., by assuring that suppliers' interests are the same as the company's, or by making it easier to transfer new technology to the supplier. The arm's-length bidding system is supposed to do a better job of keeping suppliers' prices low.

Japan's highly successful auto manufacturing industry uses the third approach, a middle way that is sometimes termed the supplier group system.[2] It consists of a pyramid, topped by the final assembler, who deals with a group of first-tier companies just below that are responsible for major components. The first-tier suppliers manage relations with the second tier, who supply individual parts and themselves often deal with third-tier groups, which may in turn reach down as far as a fourth tier of tiny firms specializing in very narrow tasks. Some of these supplier groups are tightly bound. This is especially the case with the Toyota group, composed of 225 companies that own each other's shares and lend staff and equipment from purchaser to supplier, starting with the assembler and reaching down through the various tiers. Other companies, such as Honda, have a looser structure, relying more on independent suppliers who also serve other major assemblers. But here too the relationships are close and long-term.[3]

A leading virtue of the Japanese system is that it is easier to manage than the older U.S. systems. A study for the International Motor Vehicles Program comparing General Motors procurement with Toyota's found that, despite GM's 70 percent vertical integration, and despite stringent efforts to cut back its purchasing departments, GM still had 6,000 buyers of outside components and supplies in 1987. The Toyota Motor Co., only 20 percent integrated and producing about 40 percent as many vehicles, might be expected to need as many buyers as GM but reportedly had 337.[4] These figures very likely draw an exaggerated picture of the differences, because Toyota often uses engineers as purchasing agents so that the number of its buyers is probably understated. But the disparity is so large that some of it is bound to be real, not definitional.

The answer to the seeming paradox is that, in the Toyota system and others like it, purchasing is delegated down the line. So are other responsibilities. The final assembler makes the car bodies, engines and drive trains, and integrates the system. But the first-tier suppliers are assigned the tasks of designing, engineering, and testing components, as well as producing them. Often, the supplier delivers to the assembler pre-packaged subassemblies that contain many parts (e.g., instrument panels or suspension systems). The suppliers moreover have the burdens of assuring quality and managing just-in-time delivery. What they get in return is a reliable purchaser for their particular components for the life of the vehicle model, and often beyond—subject to the understanding that they will continually reduce the component's cost while maintaining its quality. At the same time, to keep competition keen, assemblers often do business with more than one supplier of the same component.

Industries other than automating are just as wedded to the supplier group system-e. g., the manufacture of cameras (e.g., Canon), office copiers (Fuji-Xerox), personal computers and printers (NEC and Epson).[5] Figure 5-1 illustrates the supplier network for Fuji-Xerox. A rough indication of the extent of the system is that the share of Japanese

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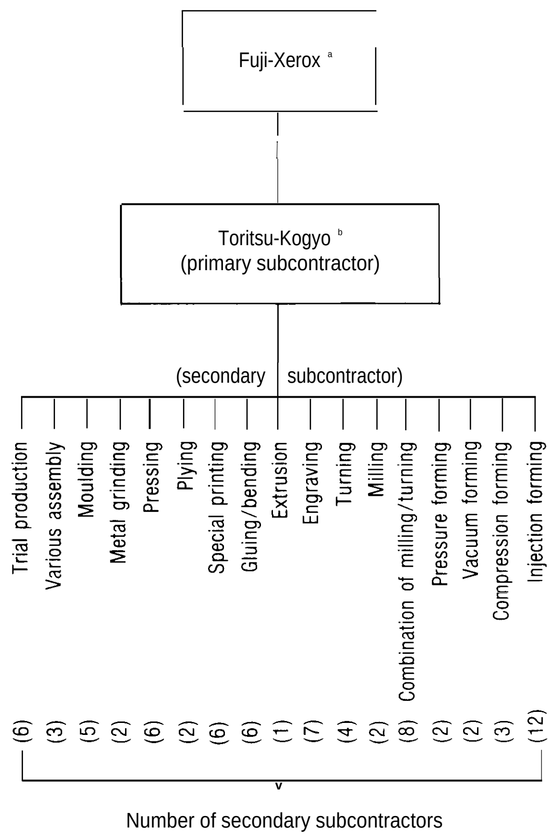
[2] The Japanesegroupsystem has been described by many authors; a comprehensive treatment of the system as practiced in the auto industry is in Michael Cusumano, *The Japanese Automobile Industry: Technology and Management at Toyota and Nissan* (Cambridge, MA: Harvard University Press, 1985), see esp. pp. 241-61. A succinct description is in James P. Womack and Daniel Roos, "Case Study: The Automotive Industry," contract report to the Office of Technology Assessment, Sept. 15, 1988; some of the material in this section on the motor vehicle industry is drawn from this report.

[3] A recent Japanese survey found that 68 percent of subcontractors had never changed their '' Pment, ' and that 53 percent had been doing business with the same parent for 15 years or more. Chusho kigyo cho cd., *Chusho kigyo hakusho* (Small and Medium Size Enterprise White Paper) (Tokyo: Okurasho instasu kyoku, 1988), p. 61, cited in D.H. Whittaker, ''New Technology in Small Japanese Enterprises: Government Assistance and Private Initiative," contract report to the Office of Technology Assessment, May 1989.

[4] Toshihiro Nishiguchi, '' Competing Systems of Automotive Components Supply: An Examination of the Japanese 'Clustered Control' Model and the 'Alps' Structure," Massachusetts Institute of Technology, International Motor Vehicles Program Working Paper, May 1987, p. 15.

[5] Ken-ichi Imai, Ikujiro Nonaka, and Hirotaka Takeuchi, "Managing the New Product Development Process: How Japanese Companies Learn and Unlearn, '' in Kim B. Clark, Robert H. Hayes, and Christopher Lorenz (eds.), *The Uneasy Alliance. Managing the Productivity-Technology Dilemma* (Boston, MA: Harvard Business School Press, 1985).

Figure 5-1-Supplier Network for Fuji-Xerox



a Has other primary subcontractors.
b Serves as subcontractor for other manufacturers.

SOURCE: Ken-Ichi Imai, Ikujiro Nonaka, and Hirotaka Takeuchi, "Managing The New Product Development Process: How Japanese Companies Learn and Unlearn," in Kim B. Clark, Robert H. Hayes, and Christopher Lorenz (eds.), *The Uneasy Alliance: Managing The Productivity Technology Dilemma* (Boston, MA: Harvard Business School Press, 1985), p. 364.

manufacturing companies using subcontracting rose from 32.5 to 37 percent from 1976 to 1981; in the electrical machinery industry, the share rose from 55 to 58 percent.[6] And subcontracting in Japan usually involves long-term relations and mutual obligations—what the Japanese call the *oyakigyo-kogaisha* relationship (literally, parent business-child company, but with connotations extending to many forms of superior-subordinate relationships).[7]

The supplier group system is doubly advantageous to the lead manufacturers. They get many of the benefits of both arm's-length subcontracting (control over costs) and of vertical integration (responsiveness to the lead company's needs). Moreover, the requirement of uniformly high quality from suppliers is part of the system of building in quality throughout the manufacturing process, rather than inspecting for defects at the end of the line. With this system quality need not cost extra, since it saves the cost of keeping large inventories of parts and requires less re-work.

Close interactions between the major manufacturer and its suppliers also helps the lead company field new models quickly, by dividing the labor of product development among many small firms with specialized skills. Shaving time off development can give a firm a crucial headstart. Firms that are first to respond to market changes and to adopt new technologies in their products open a lead that is hard for competitors to close.

In a study of the world's motor vehicle assemblers, a Harvard Business School team found that Japanese automakers take about 3.5 years to produce a new car design, compared to 5 years for American and European producers, and that the Japanese do it with half the engineering effort.[8] This takes into account the different amounts of engineering effort contributed by components suppliers in Europe, the United States, and Japan. The advantage, the study said, ''appears to lie in the strength of the Japanese supply base, and the way projects are organized and managed. Within the lead company, the main advantage lies in simultaneous rather than sequential engineering, made possible by a continuing informal dialog between people at different stages of the design process, with give-and-take in both directions. But suppliers contribute to this interactive process too. Often they take part in collective engineering and analysis of key new components 2 years before manufacture of a new model. About 1 year ahead of time, first- and second-tier suppliers

[6] Robert J. Ballon and Iwao Tomita, *The Financial Behavior of Japanese Corporations* (Tokyo and New York: Kodansha International Ltd., 1988), p. 45, citing the Ministry of international Trade and Industry, *White Paper on Small and Medium Enterprises in Japan, 1987* (Tokyo: MITI, 1987).

[7] Ibid., ch. 3. Many other authors have also described this intermediate system, between arm's-length contracting and vertical integration, in a variety of Japanese industries. For recent examples, see Nishiguchi, op. cit.; and Mari Sake, 'Neither Markets nor Hierarchies: A Comparative Study of Informal Networks in the Printed Circuit Board Industry, ' paper prepared for The First Conference of the Project 'Comparing Capitalist Economies: Variations in the Governance of Sectors," Wingspread, Wisconsin, May 1988.

[8] Kim B. Clark, W. Bruce Chew, and Takahiro Fujimoto, ''Product Development in the World Auto Industry: Strategy, Organization, Performance,' paper presented to the Brookings Institution Macroeconomics Conference, Dec. 3, 1987 (available from Graduate School of Business Administration, Harvard University).

may be brought in to run an assembly or subassembly line, to solve startup problems before actual manufacture.[9]

The supplier group system is also credited with an important role in the Japanese strategy of manufacturing a greater variety of products at lower volume than U.S.-style mass production has done, while still keeping costs competitive. This ability is particularly striking in the auto industry. When it started out in the early postwar years, Japanese auto production was, perforce, in small batches and great variety. The Japanese domestic market was small, exports were virtually nonexistent, and producers were numerous (they still are). The answer to the fragmented market and extreme competition was to develop a flexible production system within the factory. This included multi-skill training of workers and efficient layout of the factory and organization of work. It also included the supplier group system, with its collaborative engineering, just-in-time delivery, and assurance of high-quality parts and components. The result was an industry that initially succeeded in the rich U.S. market with a niche product (the well-made, economical small car), and has continued to broaden its sales appeal with frost-class entries into specialized markets (e.g., sports and luxury cars).

Today, the average annual production per model of the Japanese automakers is about 120,000, half that of U.S. producers. Since they introduce new models more often and more quickly, the lifetime production for the average Japanese model is about 500,000 units-less than one-quarter of the 2.1 million units for U.S. producers and well below the lifetime 800,000 units per model for the high-priced European specialists (BMW, Mercedes, Porsche, Jaguar, Volvo and Saab), The group supplier system is only one of the factors that make this flexibility possible, but it is a considerable one.

As for the suppliers, they also get multiple benefits from the system. Besides gaining reliable markets for their products, they often get loans of up-to-date equipment and sometimes financial help in buying it; assistance from borrowed engineers or technicians in learning how to use the equipment or organize work more efficiently; and in general a flow of advanced technology that has helped to make many first-tier suppliers first-rate industry leaders.[10] This technology transfer is not confined to the first-tier companies but frequently extends to the level of tiny family-run metalworking firms.[11]

Table 5-1 lists advantages of the subcontracting system from the participants' points of view, as reported by Japan's Small and Medium Enterprise Agency. At the top of the list, for suppliers, is a ''steady amount of orders. ' This stability sometimes extends to a change in product line. For example, one Japanese subcontractor who had worked with an electronics manufacturer for many years reported that he had changed from supplying paint and sheet metal to supplying printed circuit boards, at the customer fro's request.[12]

On the down side, the system has a high level of stress. Lead companies demand continual price reductions as well as high quality, and if a supplier fails to meet the demands, he may find his share of sales cut back (or even cut off eventually) in favor of a more compliant supplier. As noted, lead companies often have two or more firms supplying the same item, and the competition is tough. While an existing supplier may be safe from sudden shifts to a new competitor offering drastically lower prices (e.g., one electronics producer stuck with his supplier of printed circuit boards despite an offer from a newcomer of a 40 percent lower price), frequent ''requests' by the lead firm for price cuts can narrow the difference fairly quickly .13 Moreover, in a recession, the supplier is expected to make do with smaller orders, cut prices to the bone, and forgo profits. In Japan's economic downturn of 1986, profit margins for the printed circuit board industry fell from 2.5 percent of sales to 0.3 percent.[14] However, the lead company has the obligation to tighten its belt too; suppliers trust that their large customers will not squeeze them into bankruptcy.

[9]Toshihiro Nishiguchi, op. cit., p. 10.

[10]Reputable suppliers may get indirect financial benefits as well. Major manufacturers generally belong to a group that includes a large bank; loans on favorable terms from that bank are often made to a supplier on the lead manufacturer's recommendation.

[11]See ch. 6.

[12]Mari Sake, op. cit.

[13]Mari Sake, op. cit.

[14]Ibid.

Table 5-l—Main Reasons for Subcontracting, Japanese Firms, 1966

Subcontractor		Parent company	
Reasons	Percentage	Reasons	Percentage
Steady amount of orders	50.1	Know-how of contractor not held by oneself	57.6
Product design and development difficult by oneself	45.8	Efforts concentrated into best suited work	48.2
Efforts concentrated on production activities	38.7	Past business relations with and reliability of subcontractor	46.5
No worries about default or debts	27.7	Increased flexibility through size of orders	37.1
Improved reputation	26.2	Lower personnel costs and lower unit costs of products	36.5
Supply of raw materials, etc.	21.7	Small lot sizes and thus greater efficiency through production by small enterprises.	30.6
Technical assistance provided	14.7	Overly large size of own company would reduce operating rate	9.4
		Competition among subcontractors ensures high quality and lower unit price	8.8

SOURCE: Small and Medium Enterprise Agency, Survey in Division of Labor in Manufacturing Industries (Tokyo: SMEA, 1966), pp. 24-25.

Suppliers are also expected to push themselves to the limit to meet urgent needs of important customers. For example, when Fuji-Xerox changed the design of a part midway through development of a new copier, it made an "utterly insane' request for early delivery of a newly designed part which the subcontractor was able to meet only by working through the nights. The subcontractor was later rewarded with a generous payment.[15] But a more important motive for such sacrifice is the fact that the subcontractor's own future depends on the success of the lead manufacturer.

Finally, wages among subcontractors, especially in the lower tiers, are at least 25 percent lower than wages of the privileged lifetime employees of major manufacturing firms.[16] Indeed, low wages for the ''mom-and-pop' suppliers at the bottom of the pyramid has long been considered a competitive advantage of Japanese producers. An integrated company like GM could credibly claim this as a handicap--although GM presumably found advantages in vertical integration to compensate, since it competed successfully for years against Chrysler, which had a substantial discrepancy between the pay of its own employees and that of its suppliers. Recent research suggests that disparities in incomes between small and large firms are not as great as disparities in wages. The published data cover the workers' wages in small family-run companies, but not the income of the owner, who gets profits as well as wages.[17] Many of these small entrepreneurs make a good living. One investigator of subcontracting firms in the Japanese auto industry reported that owners of small firms made about 10 million yen a year ($71,000) on average, compared to 5 million yen for people of the same age and same high school education who work for big companies. In interviews with over 100 of these small subcontractors, the author found them "remarkably confident and satisfied despite their seemingly unstable position in the industrial economy."[18]

In any case, many American managers now seem persuaded that the system of buying from autonomous, but closely linked suppliers, offers benefits quite apart from wage differentials. The big three automakers are making moves toward adopting the group supplier system, or parts of it. The GM-Toyota joint venture, New United Motor Manufacturing, Inc. (NUMMI), has adopted the system successfully, largely with North American suppliers. It took time. At first, NUMMI found three times as many defects in the parts supplied by North American companies as in those coming from Japanese companies. But Toyota and NUMMI engineers worked with the 70 North American suppliers, and 4 years after the 1984

[15] Imai, Nonaka, and Takeuchi, op. cit., p. 371.

[16] Nominally, wages in establishments with 5 to 29 workers are only 57 percent of wages in firms with 500 or more workers. Controlling fOr differences in occupational employment eliminates about 20 percentage points of the 43 percent difference. The discrepancy has been growing; wages in the smallest establishments were 63 percent of those in the largest in 1965, but dropped to 57 percent in 1983. (OTA interview with officials of the National Institute of Education and Vocational Research, Tokyo, Mar. 15, 1989.)

[17] Toshihiro Nishiguchi, op. cit.

[18] Ibid., p. 21.

startup these suppliers were as good in cost, quality, and delivery times as their Japanese counterparts.[19]

For U.S. companies in general, both lead companies and suppliers, the changes involved in moving to the supplier group system are great and consequently slow. It means going from l-year contracts with specifications and drawings (sometimes dies and tooling as well) provided by the assembler to multi-year, less formal arrangements, in which suppliers are expected to help design and develop parts, continuously improve them, and respond quickly to requested changes during the model run.[20] It also means requiring suppliers to deliver just the right number of defect-free parts precisely when the assembler needs them. The just-in-time delivery system depends on getting high-quality parts, since there are no stacks of backup parts to replace defective ones. When the system works, it saves costs in storage, handling, end-of-the-line inspection, rework, and repair after sale, and the quality built in at every stage of supply up the pyramid leads to a reliable product and customer satisfaction. But the system also requires high competence on the part of suppliers and a good working relationship between assembler and suppliers. These attributes are not easy to develop overnight.

According to the General Accounting Office (GAO), Japanese auto assemblers operating in the United States impose on suppliers the rigorous expectations described above. (GAO reports that U.S. firms are also beginning to expect the same kind of quality, prompt delivery, and engineering capabilities from their suppliers.) A good many U.S. suppliers are having trouble meeting the expectations. Japanese supplier firms, accustomed to working in this way and also benefiting from longtime relationships with Toyota, Nissan, Honda, or Mazda in Japan, often have the advantage. The number of Japanese suppliers in America (some of them in joint ventures with U.S. fins) is growing fast. Of 104 Japanese-affiliated suppliers operating in the United States in August 1987, 102 answered queries by GAO. Of these, 60 had opened up for business in America since January 1981; 23 were established from 1970 to 1980, and 19 before 1970.

Some U.S. suppliers have succeeded with the Japanese transplant automakers. Of 30 representative firms GAO selected for interviews, 15 had done business with at least one of the Japanese assemblers—some in joint ventures with Japanese supplier firms. Most of these U.S. firms found big differences in the way the Japanese assemblers operated, compared with their American counterparts. The Japanese companies not only gave the suppliers added responsibilities but, several said, also kept in closer contact. Where the U.S. assemblers would send a few people on an occasional courtesy visit, the Japanese turned up often, bringing a wide range of staff to give the suppliers' operations a complete evaluation. One trim and body parts supplier said the Japanese assembler he deals with calls every day to consult on defects. A steelmaker said the Japanese company visits were "preventative" where the American company's were ''reactive. ' Most of the U.S. suppliers doing business with the Japanese transplant automakers rated the results positively. They cited benefits of greater efficiency, better quality control, and more attention to process and product improvements. Some said the experience made them more competitive, and that they were now demanding more from their own suppliers. And some noted that U.S. automakers are adopting more and more of the Japanese practices.

These positive comments came from the firms that had succeeded in supplying the Japanese companies. From less successful firms came comments that it is hard to overcome the longstanding ties between Japanese assemblers and suppliers, and that U.S. firms are at a disadvantage in culture and language. These companies feared growing competition from Japanese-affiliated suppliers now locating in the United States. Although the Japanese automakers have stated that they intend to increase the U.S. content of their cars and trucks from about 50 percent in 1987 to about 70 percent by the early 1990s, it is not clear that "U.S. content" means the products of U.S.-owned firms.[21]

[19] John F. Krafcik, ''A New Diet for U.S. Manufacturing, " *Technology Review*, Jan. 28, 1989, pp. 31-32.

[20] The following discussion of U.S. and Japanese firms supplying automakers in the United States (both U. S.- and Japanese-owned) is based mostly on U.S. General Accounting Office, *Foreign investment: Growing Japanese Presence in the U.S. Auto Industry*, GAO/NSIAD-88-1 1, March 1988.

[21] According to GAO, U.S. automakers reported that the domestic content of their cars and trucks was 86 to over 99 percent, depending on the model, in 1986; the average for the industry was about 90 percent. These figures applied to autos made in North America, including Canada, and did not include foreign-made cars with a U.S. nameplate ("captives" such as the Dodge Colt, which is Mitsubishi-made). U.S. automakers were expected to increase the foreign content of their cars to about 17 percent by 1990, GAO said.

A fundamental change in outlook would have to evolve if Japanese-style supplier relations were to become the norm rather than the exception in U.S. manufacturing. It is longstanding custom for American manufacturers to discourage-even forbid—design engineers from developing close relations with suppliers. Direct approaches to suppliers are known as "going around the purchasing department,' and are against company rules. Purchasing agents themselves are frequently reassigned to different types of supplies, so they won't develop overly cozy relations with suppliers. The ideas behind all this are, frost, that maintaining arm's-length, impersonal, strictly contract-based relations with suppliers is the best way to get a good price and keep costs down; and second, that it is unfair to give any supplier a privileged position and deny the others an equal chance. Some company officials even believe they might be subject to lawsuits if suppliers were deprived of the chance to bid for contracts.

For suppliers themselves, the Japanese-style system has distinct drawbacks as well as strong points. While some may welcome the demands for constantly improving performance combined with help in achieving it, others find the system entirely too stressful. Moreover, the American tradition of rugged individualism exerts a pull against close bonds with customer fins. Some small companies think that if their quality and delivery times improve, they should be rewarded with higher prices-not with a long-term tie to a demanding customer. Some see such ties as threatening to their independence. They would prefer to take their chances in the bidding battle rather than find themselves beholden to too few major customers. The Japanese system does make for heavier dependence on a few customers—— only tolerable, perhaps, in a situation where many suppliers trade with their major customers for 15 or 20 years .[22]

A Japanese engineer who has observed relations between large and small companies in both Japan and the United States put it this way. In Japan, small companies making parts for computers or copiers or facsimile machines are very conscious that they are in the office automation business. They carefully monitor the price they have to stay under so that their customers, the companies that assembles the machines, can be competitive. In the United States, small companies are not so conscious of being part of a whole.

Dependence may be lessening even in Japan; as economic growth has slowed, some lead companies have actively encouraged their suppliers to seek other customers. The bonds of long-term relations are still strong however. It must be remembered that the system has roots in the centuries-old tradition of mutual obligation, and that it developed over decades in the postwar period when it suited the needs of all parties quite well. The major manufacturers were growing too fast to do all their own work; the smaller companies were eager to take part in the growth, and also to get access to modern technology at a time when foreign currency was scarce and government restrictions allowed only a few firms to import the latest machinery from Europe and America. Today, the parties to the bargain still seem satisfied, on the whole, that it is working to the advantage of all.[23]

LINKS BETWEEN SEGMENTS OF AN INDUSTRY COMPLEX

A variant of the strategy of close relations between major manufacturers and their suppliers is close links between different segments of an industry complex--e.g., between the manufacturers of chemical fibers, textile producers, apparel makers, and retail clothing businesses. There is more than a shade of difference in this variant. A chain of more or less independent industries selling to and buying

[22] A 1983 survey of 1,54.() Japanese subcontractors in the metal/machining industry found that, on average, these firms relied on one large customer (parent firm) for 60 to 65 percent of their business. (D.H. Whittaker, op. cit.) Mari Sako found in her study of printed circuit board suppliers in Japan and the United Kingdom (where customer-supplier practices are similar to those in the United States) that the Japanese suppliers depended much more heavily on fewer customers. Comparing companies of similar size, Sako found that in Britain orders from the largest customer made up 6 to 25 percent of suppliers' total sales. In Japan, the largest customer accounted for 15 to 85 percent of the supplier's total sales. (Mari Sake, op. cit.)

[23] Korea and Taiwan, which are following the Japanese model of export-led growth in many ways, have not emulated the supplier group system. Korea's *chaebol are* industrial empires, typically doing business in a few related sectors, under the ownership and management of a founding father and his heirs. They do not rely on long-term, stable relations with small subcontractors but rather buy or start up new firms to meet their needs. In Taiwan, business groups are much less prominent than in Japan or Korea. The groups that do exist arc made up of rather small firms in different economic sectors, with horizontal rather than vertical relations; the same people or their relatives hold management positions in the different fins. Relations with subcontractors are not particularly close or long-lasting. (Gary G. Hamilton, Marco Orru, and Nicole Woolsey Biggart, ''Enterprise Groups in East Asia: An Organizational Analysis, ' *Shoken Keizai*, September 1987.)

from each other differs considerably from the superior-subordinate relation of a lead manufacturer and its network of suppliers. Nevertheless, even among the nominally independent members of an industry complex, a purchaser who has attractive alternatives for material supplies wields more power than the supplier. In the case of the fiber-textile-apparel complex, it is designers and retailers who hold this power. They can buy anywhere in the world. Increasingly, in the past quarter-century, they have done so. Imports account for well over one-third of what Americans spend on apparel.[24]

In nearly all high-wage countries, the textile and apparel industries face a tough challenge from poor countries. Apparel manufacture is labor-intensive. Modern textile production is less so, but the capital requirements are relatively modest—well within the means of newly industrializing countries (e.g., Taiwan, Korea) and not out of reach for some poorer ones (China). The textile-apparel industries that seem to do best in high-wage countries are those with close ties between industry segments, where firms in the supplier industry focus their efforts on responding to customers' needs.

In the United States, textile producers and apparel makers have traditionally had standoffish or even hostile relations.[25] The main concern of textile producers was to mass-produce with high-speed equipment, rather than deal individually with customers' needs. Apparel makers, if they were big enough, treated their textile suppliers as interchangeable and disposable, bargaining with numerous firms to drive the price down. This situation has begun to change. Industry leaders are realizing that closer links, from fiber production through retailing, can lower costs, lend stability to all parts of the complex, and give an edge to domestic producers.

The Quick Response system was devised by U.S. industry leaders to foster these tighter links and capitalize on the advantage of being close geographically to the big American retail market,[26] Imports (most of which are from low-wage countries) have the attraction of lower prices;[27] but there are also extra costs in doing business with importers. Besides the obvious ones—transportation, travel overseas, advance letters of credit, and extra paperwork-the long leadtimes usually involved in overseas purchases also mean extra cost. When retailers order a year ahead of time they pay carrying costs for large inventories; they lose profits when they have to mark down unsold goods at the end of the season; and they pay still more in lost sales when items the customers want are out of stock. One industry expert estimates that these costs add up to 25 percent of the value of net retail sales.[28]

The Quick Response system uses just-in-time principles to reduce these costs. It allows the retailer to start the season with a wide but shallow selection, and when stocks get low, to re-order and get fast delivery. About 80 percent of retail apparel business is in items that have a shelf life of only 10 to ***20*** weeks, either because they are ''fashion" items in styles that are quickly changed or because they are seasonal. Quick Response is most obviously a useful strategy in these lines. However, some producers of textiles for non-seasonal products, such as bedding or men's underwear, are finding that close, stable ties with their customers make it possible to cut inventories nearly to zero by just-in-time management, and thus to save costs.

24OTA's estimate of import penetration in apparel is 36 percent for 1987. It is based on dollar value, and includes freight, insurance, and import duties; shoes are not included. Other dollar value estimates of impons, which include the costs of transportation within the United States and other extras, put the import penetration ratio for clothing at 57.5 percent. See "Import Penetration in the Apparel Industry: A Technical Study,' prepared for the Fiber, Fabric and Apparel Coalition for Trade, September 1988. Import penetration is less for textiles, about 9 percent. (The apparently low figure for textile imports are misleading. Over the past 30 years, many foreign producers have switched from textile to apparel exports, because apparel has more value added. The quotas limiting imports combine textiles and apparel; textiles embodied in the apparel are not counted separately.) The combined import penetration ratio for textiles and apparel was 25 percent in 1987, according to OTA's estimate.

25This is usually not true of textile producers and industrial consumers, such as auto companies buying seat cover fabrics, or hotel chains buying carpet. Typically, U.S. textile producers keep close ties with these industrial customers, and are very responsive to their needs. This is probably one reason for the greater success of the industrial fabrics sector, compared with the apparel fabrics sector, in fending off imports.

26A consulting firm, Kurt Salmon Associates helped to devise the plan; the DuPont chemical company and Roger Milliken of the Milliken textile company have been leading champions. DuPont is an important producer of textile fibers.

27The top four textile and apparel exporters t. the United States—China, Taiwan, Korea, and Hong Kong have textile wages ranging from about 2 to 23 percent of U.S. wages; the next two-Japan and Italy-now have textile wages 30 to 40 percent above those of United States, since the fall of the dollar.

28Kurt Salmon Associates, *The KSA Perspective (New* York, NY: January 1986).

To make Quick Response work, each of the industry segments upstream not only has to cut response time in its own operations but also needs to cooperate with the purchaser or supplier next in line. The example of Greenwood Mills, a large textile firm specializing in denim, is illustrative. Until a few years ago, Greenwood bought fiber from four different suppliers, shopping around to drive the price down. Greenwood's biggest customers followed the same tactics, shifting orders among eight or nine suppliers on the basis of lowest price.

Greenwood and its suppliers and customers have since adopted a more collaborative way of saving costs. Greenwood now buys fiber from just two suppliers, who offer quality, service, and guaranteed delivery times in return for assurance of a long-term relationship. Using this system, Greenwood has cut inventories from 3 weeks to a fraction of a week and is able to hold $40 million less in stock. In the same way, Greenwood's two biggest customers are now, by mutual agreement, reliable long-term purchasers. Greenwood takes the responsibility of loading denim into the trucks in sequence so that colors always match, marking the cuts electronically, and delivering so quickly and reliably that one jeans maker cut inventory from 4 weeks to 3 days and the other got rid of its warehouse. The denim is delivered directly to the sewing room.[29]

The heart of Quick Response is responsiveness and interaction with customer firms. Another example comes from the Dan River textile mill, a company that concentrates on making high-quality apparel fabrics and emphasizes close customer relations. Individual looms at Dan River are marked for production for specified customers. And a Dan River representative was on the floor at one shirtmaker's plant so often that he was mistaken for a new employee.

A major achievement in the Quick Response program was inter-industry adoption of a common bar code standard. This allows electronic communication between retailers and producers all the way back through the supply chain. When and if the system is widely adopted, a textile mill, say, could start preparing anew order to send to apparel makers on the basis of electronic data passed back automatically from department store sales.

The close, responsive inter-industry links just now being developed in the United States have long been a feature of the Italian, Japanese, and German textile-apparel industries-the three high-wage countries that are usually considered the most successful in these industries. This is not to say that close linkages are a guarantor of success. All these industries have other features in their favor. For example, the Italian and Japanese industries benefit from a dense network of technical, organizational and financial support, private and public. The German industry has the advantage of an excellent century-old vocational education system. All three textile industries (and the U.S. industry as well) are well-equipped with modern machinery. None of these industries, even the best, is invulnerable to competition from low-wage countries. But it seems clear that suppliers' ability to respond quickly to the needs of their customers and purchasers' willingness to form stable, cooperative relations with their suppliers are part of the mix that makes these industries more competitive, and helps them to survive without constantly escalating trade protection.

LINKS BETWEEN MAJOR MANUFACTURERS AND CAPITAL EQUIPMENT PRODUCERS

A special case of linkage with suppliers is the relation between lead manufacturing companies and the firms that make production equipment for the industry. Perhaps even more than suppliers of parts and components, makers of capital equipment depend for their success on close relations with the manufacturers down the line who are their customers. In the semiconductor industry, for example, customer firms (the chipmakers) were the source of two-thirds of the ideas for advances in production equipment in the last few years.[30]

Customer firms, in turn, benefit from easy and continuing exchanges with the makers of their production machinery. Sometimes they can achieve this with foreign manufacturers, as seems to be the case in textile manufacture. The virtual disappearance of U.S. firms from production of the most important kinds of textile machinery is apparently not crippling to textile producers. But in a rapidly

[29] OTA interview with Thomas O'Gorman, President, Greenwood Mills, Dec. 11, 1987.

[30] Eric von Hip@, *The Sources of Innovation* (New York, NY: Oxford University Press, 1988), p. 4, table 1-1.

advancing high-technology industry, close links can be crucial. Already, U.S. semiconductor manufacturers are at something of a disadvantage because U.S. equipment makers have lost out to Japanese rivals, and the handicap could become greater.

The story of the U.S. textile machinery industry illustrates the dependence of equipment makers on close ties with their customers, The industry's precipitous decline was due largely to its failure to respond to customers' needs. In 1960, American makers of spinning, weaving, and knitting machinery dominated the U.S. market, accounting for 93 percent of sales. By 1986, their share was 42 percent, most of it in spare parts and ancillary machinery. Several leading firms in the industry were organized in the traditional Ford manner for mass production, with semi-skilled workers on the assembly line turning out long runs of limited kinds of machinery. The attitude of these companies toward their customers was, "This is what we make; how many do you want?"[31]

The merger mania of the 1960s also played a part in the industry's decline. During that decade, all the Big Five U.S. textile machinery firms and many smaller ones sold out to conglomerates. Rockwell International, for example, not only bought Draper, the leading U.S. manufacturer of looms, but also smaller companies such as the Textile Machine Works of Reading, PA, which made knitting machinery. Some of these companies had built their businesses on a solid tradition of close relations and good service to their customers. But the new conglomerate owners lacked both technical knowledge of the business and interest in serving individual customers.

Scanty spending on research and development was another major cause of the deline, with U.S. producers lagging well behind the R&D spending of competitors in Europe and Japan. When the American textile machinery industry was seriously challenged in the 1970s by innovative, responsive European and Japanese manufacturers, willing and able to make a wide range of sophisticated machines, it lost.

According to people in the textile industry, the retreat of U.S. textile machinery makers from the biggest part of the field (spinning, weaving, and knitting equipment) is not a serious technical handicap. They say that their German, Swiss, Italian, and Japanese suppliers keep improving equipment in response to their needs, and that service (especially from the Japanese) is outstanding. The main problem in dealing with foreign suppliers, as of the late 1980s, was the fall of the dollar, which made new equipment and parts suddenly much more expensive.

Semiconductor producers are faring worse. Japanese firms are now the world leaders in making the equipment that is most critical to chip production. According to industry sources, Nikon was not selling its leading edge model of this equipment to U.S. chipmakers in 1989, though the model was already widely used in Japan.[32]

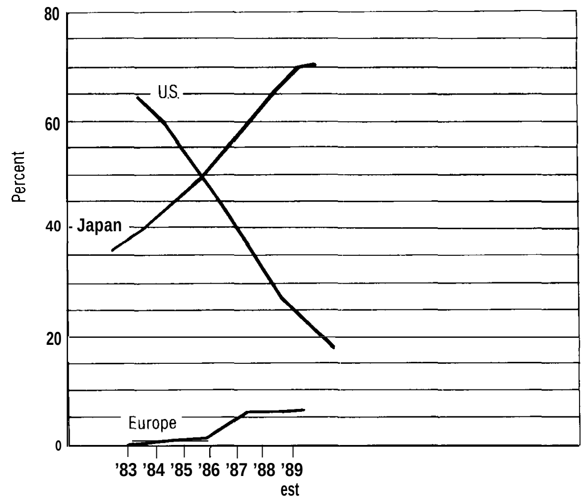
As recently as 1979, U.S. firms dominated the market for semiconductor production equipment, accounting for 79 percent of world sales. By 1989, the U.S. share was down to 47 percent and still dropping[33] (figures 5-2,5-3, and 5-4). A central part of chipmaking is the fabrication of wafers, the 2- to 8-inch silicon disks on which dozens to hundreds of individual chips are made. The most vital piece of wafer fabrication equipment is the step and repeat aligner, or stepper, which uses ultraviolet light to project an outline of the chips' circuit on the wafer; the circuit is then etched in an acid bath or reactive gas. An American firm, GCA, was first to commercialize a stepper, and it dominated the field until the early 1980s. Nikon first pulled ahead in 1983. Today, GCA (which was bought by General Signal in 1988) is out of the Japanese market, has about 5 percent market share in Europe and 20 percent in the United States. Nikon now occupies a commanding position (table 5-2). It was Nikon's latest and best stepper, the G-body, that was unavailable to U.S. firms in 1989.

[31] Charles F. Sabel, Gary Herrigel, Richard Kazis, and Richard Deeg, "How To Keep Mature Industries Innovative," *Technology Review*, Apr. 28, 1987.

[32] Principal sources for the following section are OTA'S review of the literature and interviews with leaders in the semiconductor and allied industries, and with officials of the Sematech consortium; other sources include Industry and Trade Strategies, ''The U.S. Electronic Industry Complex,' contractor report to the Office of Technology Assessment, October 1988; William F. Finan and Jeffrey Frey, ''Study of the Management of Microelectronics-Related Research and Development in Japan,' contractor report to the Office of Technology Assessment, November 1988.

[33] VLSI Research, Inc., personal communication, Jan. 5, 1990.

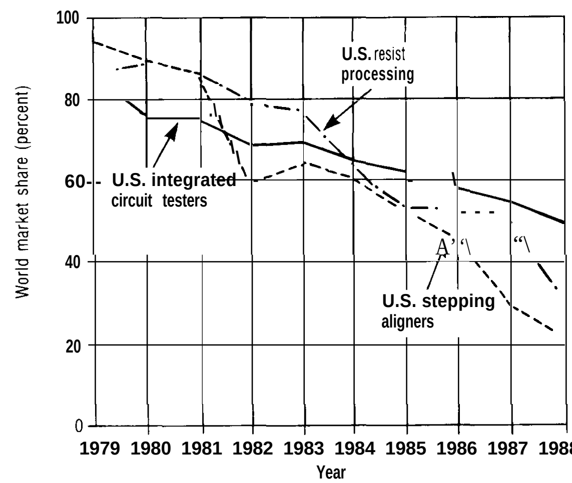
Figure 5-2--Shift in Market Shares for Wafer Steppers



NOTE: The wafer stepper is a device central to manufacturing semiconductors.

SOURCE: VLSI Research, Inc.

Figure 5-3--U.S. Market Shares of Selected Semiconductor Equipment



SOURCE: VLSI Research, Inc.

Of the several reasons why Japanese firms have bested U.S. equipment makers, a leading one is that U.S. chipmakers were themselves losing out to the Japanese competition.[34] Japanese firms began to spend more on capital equipment than their U.S. rivals in 1983, and continued to outspend American firms throughout the industry's worldwide slump in 1985 -86.[35] Increasingly during this build-up, Japanese chipmakers bought Japanese-made production equipment—in the case of steppers, overwhelmingly from Nikon. GCA, which had geared up to produce 500 to 600 steppers (at $1 million apiece) in 1985, sold barely 100 for the year, and wound up losing $94 million. Financially weakened, suffering delays in delivery of lenses from the German firm Carl Zeiss (Nikon made its own lenses), and making a stepper that was no longer clearly the world's best, GCA never recovered.[36]

How Nikon caught up with GCA technologically is another part of the story. Close relations between the maker of production equipment and the customer using it played an important role. The Nikon stepper was an outgrowth of the very large-scale integration (VLSI) project which MITI directed from 1976 to 1979. The goal of this cooperative industry-government project was to help Japanese companies master the technology for making the newest generation of semiconductors and, more broadly, to encourage the national move toward more knowledge-intensive industries.

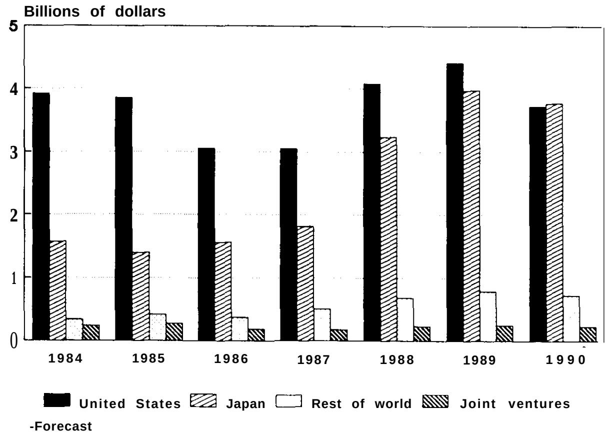
The emphasis of the VLSI project was on the manufacturing process. One-third to one-half of the budget went for purchase of equipment (including a GCA stepper), and the five chipmakers who were the

[34] In 1981, Us. merchant companies (those that produce chips for the open market, not just for their own internal use) shared the big important market for dynamic random access memory chips (DRAMs) equally with Japanese firms. By 1988, U.S. firms had 8 percent of the world merchant DRAM market (this excludes chips made by integrated firms such as IBM for their own internal use), Japanese firms had 87 percent, and most of the rest was divided between West Germany and Korea.

[35] Dataquest figures, as shown in *The Semiconductor Industry*, report of a Federal Interagency Staff Working Group (Washington, DC: National Science Foundation, 1987), p. 28, chart 24. The data cover U.S. merchant (but not captive) producers. The rate of capital spending by Japanese companies (i.e., spending on plant and equipment as a percent of revenues in the integrated circuit business) has been higher than the U.S. rate since 1982. For years before 1981, the data on rates of capital spending are in conflict. OTA's data for 11 U.S. merchant producers and 11 or 12 Japanese producers, show that the Japanese rate was higher from 1973 to 1980, and nearly the same in 1981; see U.S. Congress, Office of Technology Assessment, *International Competitiveness in Electronics*, OTA-ISC-200 (Springfield, VA: National Technical Information Service, November 1983), p. 274. According to Dataquest, the Japanese rate was about equal to the U.S. rate from 1977 through 1981 but in 1982 and thereafter was higher; see *The Semiconductor Industry*, op. cit.

[36] According t. Us. industry sources, the GCA stepper has better focus and more precise alignment than the Nikon—but only when engineers set it up. The Nikon stepper is more robust and requires far less set-up time. It can run well day after day with little adjustment, and therefore is much superior in throughput (an important consideration for mass production of commodity chips).

Figure 5-4--World Semiconductor Equipment Sales



SOURCE: VLSI Research, Inc.

main participants from industry worked hand in glove with equipment makers. The project managers selected Nikon to develop a made-in-Japan wafer stepper—a logical choice since Nikon already had a fine reputation as a maker of precision optical equipment, cameras and lenses, and also precision mechanical measuring instruments. Toshiba, the first Japanese company to have used GCA steppers on a production line, was chosen to work with Nikon on behalf of all the member companies.

The collaboration was extraordinarily close. According to a GCA engineer familiar with the effort, Toshiba set performance specifications but did not provide a design. Instead, Toshiba engineers reviewed all details of development, manufacture, and testing; provided technical help in design concepts, electronics, and materials and components selection; and in the process visited Nikon several times a week.[37] The result was a stepper which, though not radically different from GCA's, gained the reputation of being more reliable.

The close relation between vendors and users was not unique to the VLSI project. It is characteristic of the Japanese semiconductor industry, and remains a potent factor in the industry's success. The same engineers who oversee supplier companies' development of a new piece of equipment are then responsible for putting it to work on the production line, where their familiarity with it pays off in rapid achievement of high productivity and quality. This kind of collaboration is largely missing in the U.S. semiconductor industry. According to officials of Sematech, the U.S. industry-government consortium that is working on generic improvements in the semiconductor manufacturing process, the lack of close relations between equipment producers and chipmakers is a serious handicap. The consortium has given top priority to improving those relations, and to developing a full range of high-quality, reliable, affordable equipment and materials for the U.S. semiconductor industry.

Some firms-notably big ones like IBM and AT&T—have worked closely with equipment producers. But the merchant firms (those that sell chips on the open market rather than producing chips largely for their own use) have typically had arm's-length relations with their equipment suppliers. Sometimes the relations are downright distrustful; new equipment firms are often started by executives defecting from companies that manufacture chips or from other equipment firms. The Japanese firms' habit of collaboration extends to their American as well as their Japanese suppliers. Spokesmen for GCA noted that their Japanese customers were more demanding than American fins, asking for more fine-tuning and changes in the equipment they bought. But they were also more helpful in making suggestions for improving the equipment.[38]

It is worth repeating that vendor-user relations were not the only factor in Nikon's (and later Canon's) emergence as world leaders in photolithographic equipment.[39] The nearly instant preference Japanese semiconductor firms gave to the Nikon stepper, combined with the large investments in new equipment that these firms made through the mid-1980s, were critically important. In 1981, GCA had 95 percent of the Japanese market. The next year, it had 40 percent. Today it has next to nothing. Toshiba took the Nikon stepper as soon as it was out, in April 1981. NEC followed in early 1982 when

37 Finan and Frey, op. cit., citing Jon Sigurdson, "Industry and State Partnership in Japan: The VLSI Project," Discussion Paper No. 168 (Lund, Sweden: Research Policy Institute, 1986), p. 48.

38 OTA interview with GCA.

39 When Nikon first brought out its stepper, it was the only Japan_e producer; Croon stuck to making the older process aligner. Later, 8s GCA weakened, Canon entered the stepper market.

Table 5-2—Top Ten Semiconductor Equipment Suppliers, World Sales (millions of dollars)

1982		1988	
Perkin-Elmer	$162	***Nikon***	***$521***
Varian	100	***Tokyo Electron (TEL)***	***508***
Schlumberger	96	*Advantest*	*385*
Takeda Riken(Advantest)	*84*	Applied Materials	382
Applied Materials	84	General Signal	375
Eaton	80	Canon	290
Teradyne	79	Varian	211
Canon	*78*	Perkin-Elmer	205
General Signal	77	Teradyne	190
Nikon	***58***	LTX	180

(Japanese Firms Italicized)

SOURCE: VLSI Research, Inc.

prices offered by the two rivals, after intense competition, were equal. NEC said its decision in favor of Nikon was based on technical superiority, availability of local service, and early delivery. Then, when semiconductor sales nosedived in 1985, U.S. chipmakers canceled their orders for GCA steppers—a near mortal blow to a company that had just invested heavily to expand capacity.

The troubled condition of Perkin-Elmer's semiconductor equipment division, a major U.S. supplier of photolithographic equipment, underscores the point that other factors besides relations with customers are important to success in the semiconductor equipment business. For over 20 years, IBM worked closely with Perkin-Elmer on various kinds of equipment (though not the stepper, which Perkin-Elmer effectively ceded to GCA). Recently, with IBM's financial and technical help, the company developed an advanced step-and-scan machine, the MicraScan,that is said to be a technological wonder, with the potential to vault over the Japanese competition.[40] Yet despite Perkin-Elmer's technical abilities, and despite its close-working relationship with IBM, its semiconductor equipment division was a financial loser in the 3 years 1987-89 (the main part of the company's business is in scientific instruments).[41] In April 1989, Perkin-Elmer offered its semiconductor equipment division for sale.

One reason for Perkin-Elmer's decision to bow out is the heavy spending for technology development that the fast-moving semiconductor business demands; new generations of both chips and equipment appear about every 3 years. Perkin-Elmer(and IBM) spent $100 million in 4 years to develop the MicraScan, and faced costs of $50 to $l00 million more to refine and update the equipment. The high cost of capital and pressures for short-term profits in the United States add to the burden of making continuing high investments in advancing technology.[42] Nikon and Canon, Perkin-Elmer's Japanese competitors, have the advantage of easier access to low-cost capital and less pressure to show short-term profit;and both these firms excel in engineering and manufacture.

IBM declined to buy Perkin-Elmer's semiconductor equipment division, on grounds that the expertise for running a toolmaking business was outside its area of competence. No other U.S. buyers had come forward by the end of the year. Nikon; which has both the technical and financial resources to run the company, was the leading suitor but then backed off, apparently because of U.S. political objections to the sale.

The erosion of leadership in production equipment is already a handicap for the U.S. semiconduc-

[40] According t. VLSI Research, a consulting firm that specializes in semiconductor equipment, Perkin-Elmer's new machine has a 3- to 4-year lead on all the competition, including Nikon and Canon. Alan Cane, "Chips Are Down for Perkin-E1mer,' *Financial Times*, Dee. 7, 1989, p. 21; see also Andrew Pollack, "The Challenge of Keeping U.S. Technology at Home," *The New York Times*, Dec. 10, 1989, p. 1.

[41] The division had revenues of $190 million and operating losses and charges against earnings of $200 million in the three years, according to an analyst with Shearson Lehman Hutton, Inc. (Pollack, op. cit.) The Perkin-Elmer company as a whole lost money in 1987 but made a profit in 1988.

[42] See ch. 3 for a discussion of the U.S. financial environment and its effect on technology development.

[43] Korean producers, with their low-cost labor, are a bigger threat to Japan in l-megabit memory chips than U.S. manufacturers, and the Koreans are reported to be worried that their access to Japanese equipment may be restricted. (David E Sanger, "South Korea's High Tech Miracle,' *The New York Times, Dec.* 9, 1988, p. D1.)

tor industry, at least in wafer fabrication.[43] (American companies are apparently able to buy some other kinds of Japanese-made production equipment, such as automatic assembly and testing equipment, on fairly equal terms with Japanese chipmakers.) The situation could deteriorate. Microelectronics is one of the world's most dynamic industries. Chipmakers in the nation where critical new technology in wafer fabrication is first developed will almost certainly be the frost to use it, and thus will gain a vital advantage. X-ray lithography is a strong candidate for the next step, and in this emerging technology, the Japanese are well ahead.

Photolithographic steppers, used to etch today's l-megabit chips, can go up as far as 16-megabits, but the chips of the late 1990s and the early 21st century (64 megabits and beyond) will have circuitry with lines too fine for etching even by ultraviolet light. X-rays, with their shorter wave length, have much greater potential. Ultimately, chips made with X-ray technology might be able to store 1,000 times as much data as the current l-megabit chip.

Development of X-ray lithography is expensive. The Sematech consortium, for example, had to rule out extensive work on the technology because its funds-about $200 million a year over 5 years—would not stretch that far. In Japan, the half dozen leading chipmakers, several supplier firms, and the officially privatized (but still mostly government-owned) Nippon Telegraph & Telephone (NTT) were all involved in a MITI-led program to develop various aspects of the X-ray technology. In the late 1980s, the Japanese effort was outspending American efforts at least five to one, and several firms were engaged in developing a compact synchrotrons to generate X-rays at the right wave-length and intensity, at commercially acceptable costs.[44] In Japan, in 1989, ten compact synchrotrons were under construction or already at work on experimental projects, and five more were on the drawing boards. Development of a compact synchrotrons was also far along in Germany; government funds have helped support the Siemens company in its development. In the United States, only IBM was constructing a commercial-type synchrotrons, and the cost was straining even its resources. IBM invited other U.S. chipmakers to participate in the effort, and Motorola signed on in late 1989.

Commercial use of X-ray technology may very well come about in the 1990s.[45] If it does, the first commercial use will most likely be in Japan, giving that country's semiconductor producers a big lead in a new round of world competition. As the Japanese semiconductor industry itself has shown, it is possible to catchup even when one is far behind. The United States has yet to demonstrate this ability, although projects such as Sematech are a move in this direction.

INTERNAL LINKS: VERTICAL INTEGRATION, PRODUCT DIVERSITY, AND LARGE SIZE

Japanese firms are the world's leading producers of semiconductors, with 45 percent of the world market in 1989. U.S. companies, which held 53 percent in 1984, were down to 42 percent and declining[46] (see figure 5-5). Six of the world's top 10 companies in sales of semiconductors on the open market are Japanese, and all of them are large, stable, integrated electronics firms that make everything from chips to computers and consumer electronics. They make more chips than they need and sell the

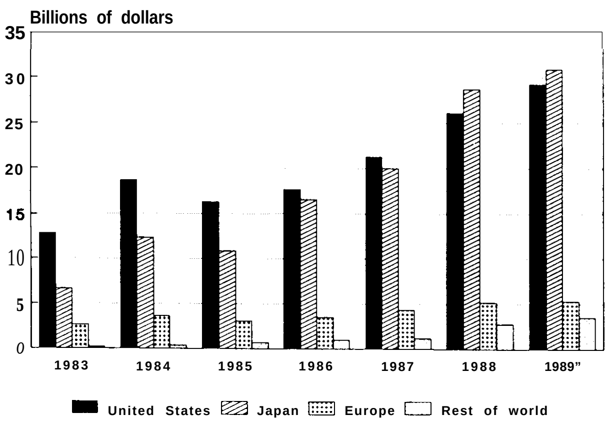
43 Korean producers, with their low-cost labor, arc a bigger threat to Japan in l-megabit memory chips than U.S. manufacturers, and the Koreans are reported to be worried that their access to Japanese equipment may be restricted. (David E Sanger, *'South Korea's High Tech Miracle,' *The New York Times*, Dec. 9, 1988, p. D1.)

44 The Japanese program had spent $500 to $750 million by late 1988, and planned to spend $200 million more; comparable figures for the United States were $50 to $100 million already spent, and $100 million planned. (John Markoff, "Experts Warn of U.S. Lag in Vital Chip Technology, " *The New York Times*, Dec. 12, 1988, p. 1.) A technology that generates X-rays by pulsed laser sources is a possible alternative to the synchrotrons, slower but perhaps more practical. Japanese R&D is also pursuing this possibility.

45 Optical (ultra-violet) lithography may last a while longer, however; Sematech is betting that it will, and is putting much of its effort into stretching the technology to its farthest limits. The history of the semiconductor industry shows that technologies sometimes last longer than expected, For example, several Japanese companies got a headstart on U.S. firms in manufacturing the 64K dynamic random access memory chip because they used an older, conventional technology while the U.S. companies were trying to get the bugs out of a newer one.

46 These figures are from VLSI Research Inc., and are for all semiconductor production, including intra-company captive production as well as merchant production for the open market. Figures from Dataquest are for merchant semiconductor production only; they show U.S. producers holding 37 percent of the world market in 1988 (down from 61 percent in 1980), and Japanese producers holding 50 percent; see National Advisory Committee on Semiconductors, *A Strategic Industry at Risk*, a report to the President and the Congress (Arlington, VA: The Committee, 1989).

Figure 5-5—World Semiconductor Sales



-Forecast

SOURCE: VLSI Research. Inc.

rest. Most U.S. companies that sell on the market are smaller, less stable, and less integrated. Some make virtually nothing but chips. Although there are large integrated U.S. companies making chips—IBM, AT&T, the Delco division of GM—they typically use most of the chips they make and buy more besides.

One explanation for the explosive success of the Japanese is the structure of their industry. It has been strongly argued that the vertical integration, large size, and product diversity of Japanese firms give them an advantage of staying power that is almost unbeatable---even if the U.S. industry succeeds in its strenuous efforts to catch up to the Japanese in manufacturing excellence.[47] Moreover, the big integrated firms can use their most advanced chips to improve their own end products (computers, work stations, robots) well before they sell the chips on the open market to competitors.

It is true that Japanese firms are using their structural features to advantage (American firms with much the same features have not been so successful, however). Possibly other arrangements—close collaborative relations between suppliers and customer firms, say--could give U.S. companies many of the same benefits that the integrated Japanese firms enjoy. These arrangements would not, however, provide the kind of financial strength that helped the Japanese firms weather the steep semiconductor recession in 1985-86. (Volatile demand, independent of the business cycle in the economy as a whole, is typical of the semiconductor industry, although the 1985-86 downturn was deeper than usual.) But it is well to remember that the Japanese industry was not always so well-heeled as it is today. One must look to other factors to explain Japanese staying power before the plush era of the later 1980s. Government support, financial and otherwise, had much to do with it. So did the well-known ability of Japanese managers to take a long-run strategic view, rather than going for short-term profits.

The supposed advantages of integration and large size are most relevant to the semiconductor industry. (Lesser integration is often proposed as a remedy for other industries--eg., the supplier group system as easier to manage and more conducive to innovation than GM-style integration in autos; mini-mills as more flexible, responsive, and efficient than the integrated behemoths of the steel industry.) But the semiconductor industry is well worth consideration on its own, for it is at the heart of technological advance in every sector of the economy, from autos to computers to banks to defense.

Links to Markets, Financial Stability

All the leading Japanese semiconductor producers belong to big, vertically integrated firms. All sell chips on the open market, but some 50 to 70 percent of the chips they make are used internally or sold to an affiliated firm in their industry group.[48] Facing competition in the open market probably strengthens their performance, and having a large, reliable demand lessens the risk in investing the $300 million or more that building a state-of-the-art semiconductor plant now requires. In addition, a big, diversified company can see its semiconductor division through periodic downturns in demand, as in 1985-86, when Japanese producers are estimated to have lost $3 to $5 billion, and U.S. producers some $2 billion in memory chips. While the demand for computers, and consequently for memory chips, plunged, the Japanese companies' sales of other electronics products such as VCRs and compact disk

[47] For an example, see Michael L. Dertouzos, Richard K. Lester, Robert M. Solow and the MIT Commission on Industrial Productivity, *Made in America: Regaining the Productive Edge* (Cambridge, MA: The MIT Press, 1989), pp. 248-262.

[48] Michael G. Borrus, *Competing for Control: America's Stake in Microelectronics* (Cambridge, MA: Ballinger Publishing CO., 1988), P. 111, table 54.

players held up. The top six Japanese semiconductor producers (NEC, Hitachi, Toshiba, Fujitsu, Matsushita, and Mitsubishi) are divisions of integrated electronics firms that had sales of $10 to $23 billion in 1987. Semiconductors accounted for only 8 to 17 percent of their sales.

The top U.S. firms are much more various. Of eight leaders (companies ranking in the top 20 for world market share), two, IBM and Hewlett-Packard, produce chips almost solely for their own use. The rest range from about 20 percent outside sales (AT&T, which recently began to push external sales) to more than 90 percent. The leading U.S. merchant producers—those that sell on the open market-range in size from medium to modest compared to the Japanese electronic giants. The two largest are Motorola and Texas Instruments, both diversified electronics firms of medium size, with total company sales of around $5 to $7 billion in 1988. Much of their chip production is for their own use but they are also big producers for the market; semiconductors count for one-third or more of their sales. The other leading merchant firms (Intel, Advanced Micro Devices, National Semiconductor, Fairchild) are primarily in the chip business.[49] They sell mostly to outside firms, and therefore lack the assurance of a large internal market. They are considerably smaller than Motorola and Texas Instruments (not to mention the Japanese electronics companies), with sales that run from about $1 billion to $2.5 billion. (IBM is primarily a computer and electronic systems company but is also the biggest of all the semiconductor producers; its total sales in all product lines were $54 billion in 1988.)

Large size, diversity of product, and vertical integration can have their down sides too; for example, bureaucratic clumsiness and top management that does not understand the semiconductor business. Indeed, in the United States, the moderate size and flexibility of entrepreneurial semiconductor firms have been hailed as the source of creativity and innovation. And, in this country at least, some highly diversified and vertically integrated companies have tried the semiconductor business with only limited success (e.g., RCA and Westinghouse). AT&T, a very large company ($34 billion in sales in 1988) with a big internal market in telecommunications equipment, recently abandoned production of DRAMs.

It seems that large size and a high degree of integration are no guarantee of success in the semiconductor business. But are they necessary even if not sufficient? (The question applies to major players in the game, not to small niche producers.) And if large, diverse, integrated firms have a built-in advantage, why hasn't the U.S. industry taken that direction? The answers to these questions are not simple or obvious. The U.S. industry developed a structure that was well-suited to an earlier period of the microelectronics business but does not fit as well with the requirements of a more mature industry. (However, other factors besides industry structure have also favored Japanese semiconductor producers as the industry matured; see the discussion below.)

The pioneering era of the business, from 1950s up to the mid- 1970s, was one of repeated technological upheaval as products were rapidly introduced and then just as quickly superseded. The germanium transistor gave way to the silicon transistor; integrated circuits ousted the single transistor for most uses; MOS (metal oxide semiconductors) succeeded and largely replaced bipolar logic in highly integrated systems, as in the memory chips used in computers. This environment of turmoil and frequent change was favorable to startups of new, creative companies bankrolled by venture capital. High turnover—20 percent a year on average, including top ranking professionals and managers as well as production workers—has been the hallmark of Silicon Valley since its early days. Engineers and scientists repeatedly peeled off and spawned new generations of highly innovative, but often short-lived, firms with a strong focus on new products. Along with the new products came substantial changes in the manufacturing process.

In about the last dozen years, microelectronics has settled down. Important changes are still occurring, but they have become more incremental than revolutionary. The 1-megabit memory chip of the late 1980s is a fairly direct descendant of the 16-kilobit chip of 10 or 12 years earlier. It is made by essentially the same methods. But making chips with ever finer lines and greater density requires ever

[49] Fairchild Semiconductor Corp., formerly a subsidiary of the international conglomerate Schlumberger, Ltd., was recently acquired by National Semiconductor Corp. The sales figures cited here are from the 1989 edition of *Standard and Poor's Register of Corporations, Directors and Executives* (New York, NY: McGraw-Hill, 1989); they do not reflect the acquisition.

more complex machinery, more exacting conditions of manufacture, and greater capital investments. The $300 million or more that it takes to build and equip a semiconductor plant for memory chips today compares with an entry cost of $5 million or so in the early 1970s.

Three characteristics of Japanese industry, apart from structure, are advantageous in the present stage of the microelectronics business. One is the demonstrated excellence of the Japanese in manufacturing. As an industry matures and incremental improvement takes the place of radical innovation, what counts most is the ability to shorten the cycle of product development, to get the latest version of a product to market quickly, and to make the product to high standards of quality and reliability, at a competitive price. This is just what the Japanese did, beginning with the sudden conquest of half the U.S. market for 16K random access memory chips in 1980 and continuing with its successors, up through the l-megabit chip. Many well-known aspects of the Japanese system of manufacturing--collaboration between design and manufacturing engineers, scrupulous attention to every detail of manufacturing, the team system for shop floor workers and their close involvement in quality and productivity, close cooperative links with suppliers, and a long-term view on the part of managers-contributed to this outcome.

Another factor is the relatively low cost of capital in Japan and the favorable conditions banks and shareholders have long offered to major manufacturers—a factor that grows in importance as capital costs rise.[50] Related to this is the long-term view characteristic of Japanese managers. The lower capital costs are, the longer a company can reasonably wait for payoffs on its investment. Also, the lifetime employment offered by large Japanese companies, and the fact that employees typically stay with one company for their entire careers, contributes to a strategy of counting on market growth for prosperity, rather than taking instant profits. The highly unstable attachment to companies in Silicon Valley pushes in the opposite direction. Still another factor, not discussed here but to be considered in a following report, is the contribution of the Japanese Government's industrial and trade policies to the success of industries considered critical to the nation's economic future—government support of R&D and assurance of a plentiful supply of low-cost capital, combined with export promotion, tight restriction of foreign investment, and protection of the domestic market.

With this perspective, it may be seen that the more-or-less assured markets for semiconductors that a vertically integrated electronics firm can offer, the stability furnished by product diversity, and the greater power to make capital investments that comes with large size are great assets for the big Japanese electronics companies, but are not by themselves *the* decisive assets. A recent example from Japan underscores the point that vertical integration is not prerequisite to success. NMB Technologies Inc. is a subsidiary of a prosperous but not very large Japanese company, Minebea, which has a $1.5 billion yearly business in precision ball bearings. Entering the semiconductor business in 1983, NMB invested $250 million in a world-class fabrication plant, and started producing superfast DRAMs in volume in 1985. Despite the world recession in chips, NMB hung on, and was ready with suitable fast memory chips when Intel and Motorola introduced their 32-bit microprocessors for top-grade personal computers in 1986. Granted, fast DRAMs are something of a niche market; yet the investment required to get into the business was far from trivial. NMB may later fall victim to a bigger company deciding to compete in fast DRAMs, but in 1989, only 4 years after starting production, it had 90 percent of the world market in fast DRAMs, and expected to double its 1988 sales of $250 million.[51]

For stand-alone semiconductor firms there maybe alternatives to the internal markets that integrated companies provide. Long-term, stable relationships between chipmakers and chip users (i.e., builders of computers, work stations, telecommunications equipment, industrial machinery, automobiles, consumer electronic goods) might offer similar benefits. An example is the close ties between IBM and Intel, which makes a microprocessor for IBM computers. NMB owed much of its success to cultivation of close links with users such as Compaq Computer

[50] The great prosperity of the Japanese electronics Companies in the late 1980s (and indeed of the entire Japanese economy) has reduced the importance of bank loans and outside equity holders; many of these companies today are capable of meeting most of their own financial needs. See ch. 3 for discussion of this issue.

[51] Larry Wailer, "How NMB Took Over the Fast-DRAM Market," *Electronics*, November 1988.

Corp. (its biggest customer) and Lockheed Aircraft Corp.

Compared with their performance in manufacturing standard commodity memory chips, U.S. producers do better in the kind of chips where individual product design and attention to customers' needs are paramount and price is secondary (e.g., microprocessors and application-specific integrated circuits, or ASICs). However, two can play at this game. The top three firms in ASIC sales are Japanese. Not only do they sell ASICs at home, they operate design centers in Boston and Silicon Valley, send the designs back to Japan by satellite communication, and deliver the custom (or semi-custom) chips by air. The greatest remaining U.S. advantage is in microprocessors, where the creative talent of designers (a U.S. strong point) is of paramount importance; also, users of microprocessors tend to form long-term ties with producers because they invest in software that fits their particular microprocessor and its progeny.

For mass-production chips, however, investments in semiconductor plants have become so huge and the sales needed to justify them so large that it may be a good deal harder for an independent. undiversified company to prosper now than it was in the past. The plenitude of capital that the large, integrated electronics companies of Japan possess may be a critical asset. It is sobering to reflect that among U.S. firms, only IBM, Texas Instruments and the much smaller Micron Technology, Inc. stuck with DRAM production through the late 1980s, and most of Texas Instrument's production was in its Japanese facilities. (Motorola was getting back into production of DRAMs in 1989, after making an agreement with Toshiba to swap a license to produce Motorola's microprocessor in return for access to Toshiba's l-megabit DRAM technology.) As recently as 1980, there were 11 U.S. companies making DRAMs. This mass-production chip is essential to computers, telecommunications, and many other kinds of equipment, and has been a favorite technology driver for the industry .52

The purpose of Sematech, the government-industry R&D consortium in semiconductor manufacturing technology, is to help U.S. producers regain competitiveness in DRAMs and other memory chips. Sematech is a novel venture for the United States; not only has it put together industry and government funding on a large scale, it is forming stronger vertical links than have existed before in the U.S. microelectronics industry and is creating unprecedented horizontal links between competitors. Sematech is confined to R&D, stopping short of manufacture. A more radical approach was the proposal by several U.S. computer and semiconductor companies, announced in June 1989, to form a consortium and produce DRAMs commercially. The project failed to attract enough computer firms as participants, however, and was abandoned in January 1990.[53]

Links With Consumer Electronics

Another question about linkage in microelectronics is whether the loss of the U.S. consumer electronics industry has deprived American chipmakers of an essential market. For Japanese chipmakers it is a huge market, taking 40 percent of production; this compares to 7 percent for U.S. producers. The decline in U.S. producers' share of the world semiconductor market does track to some extent the decline in U.S. market share of consumer electronic goods; in other words, other purchasers have not fully made up for the lack of sales to makers of television and radio sets, VCRs, compact disk players, and the like.

Up to this point, the loss of sales in consumer electronics has hurt U.S. chipmakers more financially than technologically. This is because most of the chips used in consumer electronics differ basically from those used in computers, telecommunications equipment, and other high-technology products. Analog devices, which receive an analog signal

[52]Technology drivers are chips whose manufacture provides learning experience that can then be applied to other kinds of chips or later generations of the same chip. DRAMs are good technology drivers because: 1) they are produced in large enough volume to supply data quickly for statistical analyses; 2) they are high-density integrated circuits that push the limits of current lithography technology; 3) they have a simple repetitive design, which makes it easy to test them for design or production defects; and 4) the manufacturing equipment and process technology required for DRAM production is similar to that required for other chips.

[53]Charter members were three computer manufacturers (IBM, Digital Equipment Corp., and Hewlett-Packard) and four chipmakers (Intel, Advanced Micro Devices, Nationat Semiconductor, and LSI Logic). Both Apple Computer and Sun Microsystems decided not to participate, A spokeswoman for Sun cited its "global purchasing strategy" and "existing long-term agreements with other chipmakers as reason for refusal to join. ''Electronics Newsletter," *Electronics,* December 1989, p. 17.

and amplify it, are much used in consumer electronics. Computers and the like use digital chips. At one time (until the late 1970s) this divergence was something of a handicap to Japanese semiconductor producers. While they excelled in manufacture of analog devices for their booming consumer electronics business, much of that experience did not carry over into the production of large-scale integrated circuits based on digital electronics (with the VLSI project, Japanese manufacturers got over this technological hump).[54]

Today, consumer electronic goods are changing course toward much greater consumption of digital chips. Compact disk players already use them. New generations of television sets and related products will use far more. There are about 160 million television sets in the United States, which suggests that the potential market for digital chips for television alone could be large. Semiconductor producers who fail to get into this market could find themselves at a disadvantage-but not just in the TV market. More importantly, they could fall behind in the know-how required for making successive generations of computers and their applications. This is because the core technologies for consumer electronics on the one hand, and computers plus many other advanced business products, on the other hand, are converging.

All digital chips are in the same family—i.e., they are made with similar kinds of equipment and manufacturing processes. Anyone who can meet the exacting requirements for mass-producing digital chips for consumer electronics items—high volume, low cost, high reliability—gains valuable learning experience in making similar kinds of chips, well and cheaply, for computers and other business products. The same goes for other components that computers, telecommunications, and other business products have in common with consumer electronics items. Moreover, advanced television could be the application where certain leading edge technologies—e.g., advanced displays and the new manufacturing technologies needed to make them—will be needed first.[55]

The Japanese are making rapid progress toward commercializing high definition television (HDTV), and some companies are already poised to sell an advanced version of conventional television that has much improved definition. The United States is far behind. Zenith, the last remaining U.S.-owned producer of television sets, has not yet brought to market an improved definition TV (IDTV), and is a late and uncertain entrant in the HDTV race. (Foreign-owned firms with production facilities in the United States are pursuing advanced television systems, however. The Dutch-owned Philips has an IDTV on the market, and the French-owned Thomson Consumer Electronics has demonstrated an extended definition TV.) After the Defense Advanced Research Projects Agency (DANA) set aside $30 million to encourage U.S. producers to make HDTV's, Zenith proposed to collaborate with AT&T on such a venture; a number of computer and work station manufacturers are also interested. But so far, HDTV activity by U.S.-owned companies is confined to research and the earlier states of development, with commercial production still years away.

Technology Links

Another way that a vertically integrated company may get ahead of the competition is to develop its own advanced technology, and keep it for itself. For example, both Hitachi and IBM are said to have developed some superior production equipment that they never sold or licensed to anyone else.

A similar kind of technology link is part of the rising threat from Japan to the U.S. lead in supercomputers, the fastest and most powerful of computing machines. Three Japanese electronics companies (NEC, Hitachi, Fujitsu) are narrowing the U.S. lead. These large, integrated companies make their own high-speed components. Currently the world leader, and the only U.S. company making supercomputers, is the comparatively small, stand-alone firm Cray

[54] U.S. Congress, Office of Technology Assessment, *International Competitiveness in Electronics,* OTA-ISC-200 (Springfield, VA: National Technical Information Service, November 1983), pp. 196-198.

[55] For details, see the section on advanced television in ch. 2, and OTA's forthcoming report, *The Big picture.*

Research Inc.[56] Cray does not make the high-speed components needed for supercomputers, and they are hard to get from other U.S. companies. This is one of the main reasons why the U.S. lead is evaporating, according to a report by a panel of computer science experts to the Institute of Electrical and Electronics Engineers, Inc. (IEEE) .57 The report said:

> The highest performance memory and bipolar logic components useful for supercomputers . . . are available only from Japan. The managements of Cray and ETA have been quoted in the press at various times as stating that these Japanese components are "not yet available for export' from Japan to Cray or ETA as devices-but they are available to end users in the Japanese supercomputer systems. Those systems are definitely available for export.

A senior NEC manager, Akihiro Iwaya, underscored the point in an interview with *The New York Times.* He said: "We have our own chip divisions. They can custom-make the high-speed chips we need. Cray can't. They have to buy them from Japan. '[58]

Officially, Cray managers have no complaint about their Japanese suppliers. And indeed it is unlikely that Japanese producers would cut off supplies to Cray, partly because that would cause political troubles for Japan, and partly because sale of the chips is highly profitable. What is more likely is delay in providing the latest and best chips to Cray. According to one informed observer, both the Japanese firms are delaying up to a year in providing their latest chips to their American competitor.

Cray is under challenge from larger, more integrated companies in another way as well. Cray gained its leading position in supercomputers by its excellence in what the industry calls packaging, that is contriving to arrange chips in close quarters for speedy operation, while draining away the heat they generate. While Cray still has the reputation for outstanding engineering, it is facing very tough competition from bigger companies that make a full line of computers, from mainframes down through personal computers. Such companies can afford to devote a lot of engineering talent to solving packaging problems, since the results can eventually be applied not just to supercomputers but to the full line, and the costs recovered from this broad range of products. The same consideration may apply to other kinds of R&D spending as well, Not all of this particular advantage resides in Japan, however. IBM too makes a range of computers, and is supporting the efforts of a former Cray engineer (Steven Chen) to build a new improved supercomputer.

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[56] The still smaller ETA, a subsidiary of Control Data Corp., dropped out of supercomputer production in April 1989. Also, in May 1989, Cray Research spun off anew company, Cray Computer, to be run by Seymour Cray, the founder and chief designer of Cray Research. Funded by Cray Research with $100 million over 2 years, the new company was setup to pioneer a promising but risky technology based on gallium arsenide chips. Reportedly, the reason for the move was to free Seymour Cray from the short-term pressures of Wall Street. (Alan Kane and Louise Kehoe, 'Challenge to the U.S. Brains Trust," *Financial Times,* May 18, 1989.)

[57] IEEE/USAB Committee on Communications and Information Policy, "U.S. Supercomputer Vulnerability, ''report to the Institute of Electrical and Electronics Engineers, Inc., prepared by the Scientific Supercomputer Subcommittee, Committee on Communications and Information Policy, United States Activities Board (Washington, DC, August 1988).

[58] David E. Sanger, ''A High-Tech Lead in Danger, ' *The New York Times,* Dec. 18, 1988, sec. 3, p. 1.

Chapter 6

Technology Transfer and Diffusion: Some International Comparisons

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Chapter 6

Technology Transfer and Diffusion: Some International Comparisons

Compared to our strongest competitors, the United States is lacking in institutions to diffuse technology to manufacturing companies. This is true in both the public and private sectors, and it applies especially to small companies. For example, scattered Federal and State efforts to help small U.S. firms raise their technological level are no match for the dense nationwide program of financial and technical assistance to smaller manufacturers in Japan. Not many major U.S. manufacturers give their suppliers technical help, as Japanese firms customarily do. Nor is there anything in this country to compare with the apprenticeship training taken by half the young people of Germany and Sweden and credited with producing a high level of technical skills in the work force. In those countries, good worker skills are a key factor in the diffusion of manufacturing technology.

Large companies as well as small ones suffer from failures in technology transfer. With their typically standoffish relation to suppliers, large U.S. manufacturing firms rarely get the benefit of collaboration with suppliers on developing and applying new technologies —a common practice in Japan (see ch. 5). Moreover, many U.S. firms are not as good as their foreign competitors at scanning the outside world for new technologies that would improve their company's products or manufacturing techniques. Often, the company culture is inimical to anything Not Invented Here—the NIH syndrome.

There is one kind of technology transfer in which American companies do have an excellent track record. That is in taking fundamentally new ideas out of the laboratory and using them as the basis for new families of products. Whole industries have been founded on science-based inventions. For example, the transistor, an invention that depended on accumulated knowledge in quantum mechanics and solid-state physics, was the progenitor of the complex of microelectronic industries, including semiconductors and computers. In the same way, commercial biotechnology has risen on the foundation of scientific advances in molecular biology.

But U.S. firms are weaker at the more ordinary kind of technological advance in which improvements are added bit by bit to existing products and manufacturing processes. Over the past quarter century, Japanese manufacturers have repeatedly beaten American producers with incremental product and process improvements-first in transistorized radios and TVs, then autos, now semiconductors.[1] Some companies in Europe also excel at this kind of evolutionary advance. For example, the Germans, with their mastery of mechanical engineering and metalworking, are leaders in making high-quality industrial machinery.

The strengths and weaknesses of American firms in adopting new technologies reflect our institutional biases. U.S. Government science and technology policy is light on technology diffusion and heavy on the traditional government missions of defense, health, and basic research.[2] In the private sector, there is plenty of venture capital to support attempts to commercialize science-based innovations coming out of research labs, and there are plenty of footloose managers and engineers ready to shift to promising new ventures. Thus, public policy supports the kind of R&D that sometimes leads to technological breakthroughs, and private institutions are suited to exploiting them commercially.[3] What is lacking is a web of institutions to spread throughout manufacturing, to small as well as large firms, the more mundane and more gradual improvements in technology that spell success in the later phases of a product's lifecycle.

[1] Japanese success is not confined t. improvements of familiar products. For example, although the video cassette recorder was a descendant of the U, S.-made Ampex commercial video tape recorder, it embodied so many new engineering ideas that it might be regarded as a new invention. And more and more, the Japanese are putting efforts into scientific work as the basis for new technologies, as in high-temperature superconductivity.

[2] For a discussion comparing "mission. oriented' technology policy (as practiced in the United States, Britain, and France), "diffusion- oriented" technology policy (Germany, Sweden and Switzerland), and a combination of the two (Japan), see Henry Ergas, "Does Technology Policy Matter?' in Bruce R. Guile and Harvey Brooks (eds.) *Technology and Global Industry: Companies and Nations in the World Economy* (Washington, DC: National Academy Press, 1987).

[3] At least, the institutions are suited t. supporting start-up firms. However, high-tech start-ups often falter in the transition to large-scale production.

Government technology policies in other countries are much more strongly directed toward technology diffusion than are U.S. policies. Japan's long-established programs of general financial assistance to small firms and special measures to encourage small manufacturers to adopt modern technologies are of particular interest. Although there are many differences between small manufacturers in Japan and the United States, some features of the government programs that have worked well there might be translated into American terms.

Small firms have received special attention from the Japanese Government for several reasons. First, they are numerous. The Japanese economy as a whole is heavily weighted to small fins, and this is true of manufacturing as well. Small and medium size firms account for three quarters of manufacturing employment in Japan, compared to a bit over one-third in the United States. Also, small Japanese firms have often been technologically backward, paid low wages, and operated under primitive working conditions. Despite these disabilities, many small Japanese manufacturers have turned in remarkable performances-especially those that are suppliers for Japan's world champion industries (e.g., electronics, automobiles). Technology assistance given by the major customer firms has helped the performance of these supplier companies, but the government's technical and financial assistance programs get much of the credit too.

Many of Japan's large firms have now entered the ranks of the richest and most successful in the world and no longer need much of the government assistance that helped them get established. More of the nation's resources, public and private, are available to smaller fins. This chapter describes at some length the extensive technical and financial programs available to small Japanese firms today, keeping in mind their possible relevance to U.S. policy. The relatively sparse Federal and State technical and financial assistance available to small manufacturers in the United States is described in chapter 2 and chapter 7.

DIFFUSION OF ADVANCED MANUFACTURING EQUIPMENT

One measure of technological sophistication in manufacturing is the presence of advanced equipment—such things as computerized machine tools, robots, flexible manufacturing cells. This is only one kind of measure, and by no means a complete one. Other factors, especially the so-called soft technologies involving organization of work and use of people, are at least as important as hardware to manufacturing performance. Nevertheless, an industry that falls behind the international competition in installing advanced machinery will very likely find itself falling behind in the cost, quality, and variety of its products.

In the use of robots-defined as programmable, multifunctional manipulators—U.S. industries are far behind the foreign competition, especially the Japanese.[4] Although the invention and first use of industrial robotics was in the United States, it is no more than a minor factor in American manufacturing today. Even in Japan, where robots have been adopted far more aggressively, they are mostly confined to special uses in a few industries (mainly autos and electronics). A much more broadly used technology is numerically controlled and computer numerically controlled (NC and CNC) machines (also invented here). These machines are the kind of computerized production equipment most commonly found on manufacturing shop floors in the United States, West Germany, and Japan (and in other industrialized countries as well).

American manufacturers are closer to their top foreign competitors in the use of NC machines than in robotics.[5] However, Germany leads by a fair margin, and the margin is wider if U.S. military production is omitted. The Japanese, who started later than American firms in adopting NC machine tools, were nearly even by the late 1980s and were on a faster track. In a few years, unless things change, NC machine tools will be more common in Japanese factories than in American ones.

In 1988,41 percent of U.S. manufacturing establishments with 20 or more employees in five major

[4] Kenneth Flamm, "The Changing Pattern of Industrial Robot Use, " in Richard M. Cyert and David C. Mowery (eds.), The *Impact of Technological* Change *on Employment and Economic Growth* (Cambridge, MA: Ballinger Publishing Co., 1988); Edwin Mansfield, Department of Economics, University of Pennsylvania, "Technological Change in Robotics: Japan and the United States, " *Managerial and Decision Economics,* Special Issue, spring 1989, pp. 3-12.

[5] In the following discussion, the term NC includes CNC.

industry groups were using one or more NC machines, according to a survey by the Bureau of the Census.[6] The figure for German plants of the same size in a similar group of industries is 48 percent.[7] The Japanese data are shown on a different basis, that is, NC machine tools as a percent of all the machine tools in the shop. In 1987, 12.2 percent of machine tools in Japanese establishments with 50 or more employees in metal machining industries were NC. The comparable figure for U.S. establishments of the same size, at the same time, was 13.1 percent[8] (tables 6-1 and 6-2). The seeming parity of U.S. and Japanese metalworking plants in ownership of NC machine tools may be misleading, however, since the Japanese firms are acquiring the machinery at a faster rate. U.S. metalworking firms increased their installed computerized automation (mostly machine tools) at an estimated rate of nearly 16 percent a year from 1983 to 1988;[9] the Japanese added NC machine tools at a rate of 24 percent per year from 1981 to 1987.[10]

Another complicating factor in making these comparisons is U.S. military procurement. The Census Bureau's survey of U.S. metalworking establishments found that plants producing for the military are more likely than the general run of plants to use NC machines. Of all the plants in the survey, 41 percent used this automated machinery.

Table 6-l-Adoption Rates of NC Machine Tools in Five Major industries, United States (1988) and West Germany (1986)

Size of establishment (number of employees)	West Germany (percent)	United States (percent)
Under 20	15.8	
20-29	36.0	35.9
100-499	55.9	50.0
500 and over	87.3	69.8
20 and over	47.7	41.4

NOTES: "Adoption hate" means the percentage of surveyed firms reporting installation of at least one NC machine tool. "NC machine tools" include CNC machine tools.

The five major industry groups are SIC 34-36 (Fabricated Metal Products, Industrial Machinery and Equipment, Electronic and Other Electric Machinery, Transportation Equipment, and instruments and Other Related Products) for the United States. The German industry groups are similar although they may not be identical.

n.a. = not available.

SOURCES: *West Germany*: Hans-Jürgen Evans, Carsten Becker, and Michael Fritsch, "The Effects of Computer-Aided Technology in Industrial Enterprises: It's the Content that Counts," in Ronald Schettkat and Michael Wagner (ads.), *Technical Change and Employment* (New York, NY: de Gruyter, in press), and Michael Fritsch, Technische Universität Berlin, personal communication. United States: U.S. Department of Commerce, Bureau of the Census, *Manufacturing Technology 1988*, SMT (88)-1 (Washington, DC: Department of Commerce, 1968), table 6-B.

For plants making products to military specifications, the figure was 58 percent; for those making no mil spec products, only 36 percent reported using NC machines. Similar discrepancies were reported

[6] U.S. Department of Commerce, *Manufacturing Technology* 1988, Current Industrial Reports, SMT (88)-1 (Washington, DC: U.S. Government Printing Office, 1989). The survey covered 10,526 establishments, selected to represent a total universe of 39,556 manufacturing establishments in SIC Major Groups 34, fabricated metal products; 35, industrial machinery and equipment; 36, electronic and other electric equipment; 37, transportation equipment; and 38, instruments and related products.

[7] Hans-Jürgen Ewers, Carsten Becker, and Michael Fritsch, "The Effects of the Use of Computer-Aided Technology in Industrial Enterprises: It's the Context That Counts, ' in Ronald Schettkat and Michael Wagner (eds.), *Technical Change and Employment (New* York, NY: deGruyter, in press), and personal communication, Michael Fritsch, Sept. 21, 1989.

[8] For the United States, data are from the 1987 National Survey Data about Machine Tool Use in Manufacturing Plants in Maryellen R. Kelley and Harvey Brooks, *Modernizing U.S. Manufacturing (Cambridge,* MA: MIT Press, forthcoming), and personal communication, Maryellen Kelley, Sept. 20,1989. The survey covered a representative sample of establishments of all sizes, including 1,368 metalworking plantsin21 industries. "Computerized automation' in the study was defined to include programmable numerically controlled (NC) machine tools, whichare controlled by tape and have been commercially available for more than 20 years; computer numerically controlled (CNC) machine tools, which include a microprocessor and a keyboard at the machine, so that programs can be written and edited at the machine; and flexible manufacturing systems (FMSs), which consist of a number of programmable machines (either NC or CNC) connected by automatic materials handling devices (e.g., conveyors or robots). At the time of the survey, 38 percent of computerized machine tools in use were the older NC type.

For Japan, data are drawn from a survey covering establishments of 50 or more employees in metal machining industries, conducted every 6 years by the Ministry of International Trade and Industry (MITI). The MITI survey, like the Kelley-Brooks study, combines NC and CNC machine tools. Data from the two surveys are only roughly comparable, because the industries covered differ somewhat. The source for the data in English is D.H. Whittaker, ''NC/CNC Penetration in Japanese Factories," Appendix 1 to "New Technology in Small Japanese Enterprises: Government Assistance and Private Initiative," contract report to the Office of Technology Assessment, May 1989. In Japanese, the source is Tsusansho, *Showa* 62 *nen dainanakai kosaku kikai setsubito tokei chosa hokokusho* (Report of the 7th Survey on Machine Tool Installation) (Tokyo: Tsusan todei kyokai), Appendix 1, pp. 282-284.

[9] Maryellen R. Kelley and Harvey Brooks, *The State of Computerized Automation in U.S. Manufacturing*, Harvard University, John F. Kemedy School of Government, October 1988, p. I-6. The average annual rate of adoption from 1968 to 1983 was 13.7 percent, with a slowdown in the years 1973-78 (8.4 percent per year) and a speedup in 1978-83 (18,6 percent per year). Anderson Ashburn, "The Machine Tool Industry: The Crumbling Foundation," in Donald A. Hicks (cd.), /s New *Technology Enough* (Washington, DC: American Enterprise Institute for Public Policy Research, 1988), p. 55. Sources of the data are the 10th through 13th American Machinist Inventories.

[10] MITI surveys feud that Japanese plants in metal machining industries had 4,861 NC/CNC machine tools in 1973, 19,549 in 1981, and 70,465 in 1987. Whittaker, op. cit. and D.H. Whittaker, ''Machine Tool and NC Development in Japan, " mimeo, n.d.

Table &2—Penetration Rates of NC Machine Tools in Manufacturing Industries, United States and Japan, 1987

Size of establishment (number of employees)	United States (Percent)	Japan (Percent)
Under 50	8.1	
50-99	12.6	10.7
100-299	13.7	11.2
300-499	12.7	12.6
500-999	12.3	13.5
Over 1,000	13.8	12.8
Total over 50	13.1	12.2

NOTES: "Penetration rate" means the ratio of NC machine tools to the total number of machine tools installed in the establishments surveyed. "NC machine tools" includes CNC machine tools. The metalworking industries surveyed are similar but not exactly the same in the United States and Japan.

For Japan, the category "other machine tools" was excluded In this table, because it was not included in the U.S. survey.

n.a. = not available.

SOURCES: *Japan:* Ministry of international Trade and Industry, *Report of the 7th Survey on Machine Tool Installation (Showa 62 nen dainanakai kosaku kikai setsubito tokei chosa hokokusho)* (Tokyo: Tsusan todei kyokai), pp. 282-84; The source in English is D.H. Whittaker, "NC/CNC Penetration in Japanese Factories," Appendix 1 to "New Technology in Small Japanese Enterprises: Government Assistance and Private Initiative," contractor report to the Office of Technology Assessment, May 1989.

United States: 1987 National Survey Data about Machine Tool Use in Manufacturing Plants; Maryellen R. Kelly and Harvey Brooks, *Modernizing U.S. Manufacturing* (Cambridge, MA: MIT Press, forthcoming), and Maryellen R. Kelly, Carnegie-Mellon University, personal communication.

by prime defense contractors and subcontractors for their military and non-military products (table 6-3). This means that NC machines are used in American plants much more for producing military goods than for commercial goods, and thus contribute less than it might appear to the Nation's trade performance and competitiveness.

The differences in NC machine tool use in the United States, Germany, and Japan reflect differences in government policy. The policy with most effect in the United States is satisfaction of military needs. Numerical controls for machine tools were invented here in the 1940s, and MIT developed a highly sophisticated version for the Air Force in the 1950s. NC machining offered the great precision that was needed for making integrally stiffened wing skins for aircraft. The first substantial use of NC machining, in the late 1950s, was in five-axis milling machines that could hollow out the wing, leaving stiffeners in place, and contour the outside skin to the airfoil shape—all in one piece from a solid thick plate of metal (an advance from the old method of riveting the skin to ribs and stringers). The Air Force bought the first 100 of these machines (after the aircraft industry refused to invest in them) and put them in its contractors' factories.[11] Around the same time, other machine tool builders were developing simpler, cheaper, more flexible machines, taking advantage of the progress in NC controls.

Just as defense contracts were critical in developing NC machining, military requirements have had a continuing effect on its diffusion. The U.S. Government has given little attention to specific policies that would promote adoption of NC technology outside the military-industrial complex. An exception, perhaps, was the investment tax credit, in effect off and on from 1962 to 1986, that allowed firms to deduct from their income tax 7 to 10 percent of the price of any productive capital equipment, including machine tools. There is some evidence that the investment tax credit may have encouraged orders for NC machine tools. 'z

Many people expected NC machine tools to sweep U.S. metalworking shops soon after their invention. They did not. Nevertheless, diffusion of these machines has not been slow by historical standards.[13] Says Ashburn Anderson, an expert on the machine tool industry, "It is not so much that technology diffuses more slowly in the United States than in the pastas that it now diffuses more rapidly in Japan."[14]

Early on, the Japanese licensed NC technology and within 10 years had adapted the American invention into simple, cheap, and robust machines of their own design. Computerized controls (also a U.S. invention) were added in the 1970s, and Japanese firms became the world's premier producers of sturdy, relatively inexpensive workhorse CNC machine tools. The Japanese Government supported these efforts, contributing generous amounts to research and development consortia, and encouraging the thousands of small firms making machine tools to coalesce and specialize in different segments

[11] A. Anderson, Op. Cit., pp. 44-47.

[12] A. Anderson, op. cit., pp. 69-71.

[13] See, for example, Edwin Mansfield, "The Diffusion of Industrial Robots in Japan and the United States," mimeo, n.d., which found that it took the relatively short time of 5 years for half the major potential users to adopt NC machine tools.

[14] A. Anderson, op. cit., p. 79.

of the market to achieve economies of scale. (This advice was not always heeded; firms tended to stay small, but they did specialize more.)15

At the same time, Japanese government policy actively supported widespread adoption of NC machine tools. The government's equipment leasing systems bought machine tools and leased them at low rates to small and medium-size manufacturers, thus providing both a stable market for machine tool builders and subsidies for machine tool users. The government also provided low-cost capital to a quasi-public leasing company that bought machine tools and leased them to companies of any size. Japan's nationwide technology extension services (discussed below) have helped small firms learn to use the equipment effectively. In addition, Japanese tax law was changed in 1984 to allow very rapid depreciation of investments in high-technology equipment (including NC machine tools) by small and medium- size firms. This seems to have set off a flurry of buying; one Japanese manufacturer calls it the "NC-ization period. "

In Germany, emphasis in many industries on medium batch production rather than mass production may account in part for high adoption rates of NC machine tools (hard-wired automation is often more efficient in mass production) but basically, both the production and use of NC machine tools reflects Germany's tradition, more than a century old, of excellence in vocational and technical training. The German training system is supported by both government and industry; it includes 3-year apprenticeships from ages 16 to 19 for operators and further rigorous training, practical and theoretical, for the master craftsmen who become foremen and often middle managers.

Production machinery is an important export for Germany, and that includes CNC machine tools at the high end of the range. Germany's dominance in producing these complex and costly machines is due in large part to the quality of its workers. The training system also pays off in the use of NC machine tools. A study of matched metalworking plants in Germany and Britain (described in *Chapter* 4: *Human Resources)* found productivity two-thirds higher in the German plants, with most of the difference credited to training, especially of foremen. Computerized machinery worked far more smoothly in the German plant, with little downtime.

Table 6-3-Defense Production and Use of NC Machines in U.S. Manufacturing Establishments, 1988

	Number of establishments	Percent using NC machines
All establishments	39.556	41.4
Products made to military specifications		
Yes	14,588	58.1
No	19,439	36.1
Don't know[a]	2,141	38.4
Not specified	3.388	1.5
Prima defense contractor		
Yes: percent of products shipped to defense:		
1 to 25 percent	10,010	51.7
26 to 75 percent	1,012	62.5
Over 75 percent	683	61.2
Don't know[b]	601	37.3
No	22,874	41.2
Don't know[c]	1,028	42.0
Not specified	3,349	2.0
Subcontractor to defense		
Yes: percent of products shipped to prime defense contractor		
1 to 25 percent	11,533	53.7
26 to 75 percent	2,738	67.1
Over 75 percent	880	67.4
Don't know[b]	1,83	44.3
No	12,901	32.9
Don't know[c]	6,070	42.0
Not specified	3,605	4.1

NOTE: "NC machine tools" includes CNC machine tools.

a "Don't know" means the respondent didn't know what percentage of products are made to military specifications.

b "Don't know" means the respondent didn't know what percentage of products in the plant are shipped to Federal defense agencies or to prime contractors of defense agencies.

C "Don't know" means the respondent didn't know whether any of the plant's products are shipped to Federal defense agencies or to prime contractors of defense agencies.

SOURCE: U.S. Department of Commerce, Bureau of the Census, *Manufacturing Technology 1988*, Current Industrial Reports, SMT (88)-1 (Washington, DC: US Government Printing Office, 1989).

To summarize: the U.S. Government policy with most effect on both the invention and diffusion of CNC machine tools has been concern to meet military requirements. In Japan, the government supported efforts by machine tool builders to make incremental improvements in the known NC technology, and it underwrote diffusion of the technology to machine tool users through subsidized leasing, tax breaks, and technology extension services to smaller firms. In Germany, training was the

[15] For a detailed account of the development of NC controllers and machine tools in Japan, see Ezra Vogel, *Comeback (New* York, NY: Simon & Schuster, 1985).

most important contribution the government made to the production, diffusion, and effective use of computerized equipment.

None of this means that government policies were the only or most important factor in either the development or diffusion of NC machine tools in these countries. A great deal depended on the private actions and decisions of the companies and people involved. For example, Fanuc, under the direction of Dr. Seiuemon Inaba, has from the start combined excellence of product with exemplary manufacturing practice, in which the latest automated equipment is used to make reliable, inexpensive controllers. (In Fanuc's factory near Mount Fuji most of the machining and some of the assembly is done without operators.) American NC machine tool builders have been much slower to install the very kind of equipment they make-a case of the shoemaker's child, according to Anderson. Most important, Japanese designers applied microprocessors (an American invention) to CNC controls in 1976, a full 4 years before U.S. companies followed suit. That 4-year lead was probably decisive in giving Japanese NC machines first place in the U.S. market.[16] In 1988, half the NC machines sold here were made in Japan and, according to preliminary estimates, the Japanese share of the U.S. market rose to two-thirds in 1989.

Finally, the point that hardware is only one part of manufacturing success bears repeating. For example, studies of auto assembly plants in Japan, North America, and Europe for the International Motor Vehicles Program found that automation and a "lean' Japanese-style management system are each, separately, important factors in manufacturing performance.[17] But they contribute most to high productivity and high quality when they occur together. The best performing, world class companies (mostly Japanese) first established a lean management system, and then improved their performance with higher levels of automation. U.S. and European companies that automated first and then tried to improve their management of people and organization of work had a harder time reaching top performance.

LOOKING OUTSIDE THE FIRM FOR NEW TECHNOLOGIES

Incremental improvement of an existing product is part of the "cyclic development process" in manufacturing.[18] It is engineering-dominated, compared to the science-dominated process of making commercial products from radically new technologies bred in the laboratory. Despite its less dramatic character, cyclic development is no less significant than radical breakthroughs, for its cumulative effects can be profound. For example, just 20 years ago, memory chips held 1,000 bits. The newest generation of commercial chips are capable of holding 4 million bits.

If U.S. manufacturing firms have fallen behind foreign competitors in pursuing cyclic development, one reason is their backwardness in exploiting technological advances that originate outside the company (the NIH syndrome). A well-known study comparing R&D in a random sample of major firms, 50 Japanese and 75 American, found that the Japanese companies spent less time and money than their U.S. counterparts in developing new products and processes.[19] But the Japanese advantage lay entirely in innovations based on external technology. For innovations based on technology developed internally, U.S. companies performed as well as the Japanese. (The study did not attempt to assess what opportunities these large U.S. firms might have missed altogether because of their weakness in exploiting external technologies.)

The timing demands of the product development cycle suggest a possible reason for this seemingly impervious attitude. Ralph Gomory, former chief scientist for IBM, explains it this way:

> If you want to get new ideas into the development and manufacturing cycle from outside, timing is

16A. Anderson, op. cit., p. 58.

17John F. Krafcik and John Paul MacDuffie, ' 'Explaining High Performance Manufacturing: The International Automotive Assembly Plant Study,' paper presented to the IMVP International Policy Forum, May 1989, available from International Motor Vehicles Program, Massachusetts Institute of Technology, Cambridge, MA. The authors described the lean production system as one ' 'that runs 'lean' in its avoidance of problem-hiding buffers and stays 'fragile' in its willingness to rely on a skilled, flexible, motivated workforce for problem-solving and continuous improvement. "

18This term and much of the following discussion is drawn from Ralph E. Gomory, ''Reduction to Practice: The Development and Manufacturing Cycle," in National Academy of Sciences, National Academy of Engineering, Institute of Medicine, and National Research Council, *industrial R&D and U.S. Technological Leadership* (Washington, DC: National Academy Press, 1988).

19Edwin Mansfield, "Industrial Innovation in Japan and the United States, " *science,* Sept. 30, 1988.

> crucial. . . . You must propose these ideas at the *beginning* of the cycle. . . . Halfway through is too late . . . no matter how good the proposal, The company is not going to interrupt the cycle, delaying the whole project by a year and thus ending up with a noncompetitive product.[20]

It may seem that this constraint should apply to Japanese as well as to U.S. manufacturers. If it does not, or does less, one reason is that major Japanese industries contrive to keep the product cycle shorter. Thus, the point at which new ideas can be plugged in comes around faster. As noted in chapter 5, U.S. and European auto manufacturers typically take 63 months from design to introduction of a new model, while Japanese producers, on average, take 42 months-and use fewer engineering hours to do it. Likewise, Japanese electronics companies gained a critical advantage in the early 1980s when they got the 64K Dynamic Random Access Memory (DRAM) chip to market faster than most American producers; their success in taking the lion's share of this market early was one of the factors that drove all but three U.S. companies out of DRAM production. A shorter development cycle can be a particular advantage in a fast-moving field. The company that gets a product incorporating the latest technology to market soonest reaps the reward of the innovator-even if it was not the source of the new technology and has no monopoly.

Two of the major factors that enable leading Japanese companies to cut short the development cycle and get new products to market fast are in brief: 1) the supplier group system, in which subcontractors take on some of the design and development burden; and 2) frequent, close communication between the product designers and manufacturing engineers and rotation of people from design to production. This second feature may be thought of as a form of technology diffusion itself, one that takes place within the company.

The time constraints of the development cycle mean that people inside the firm must be instigators in collecting new technologies from the outside world. They are the only ones who know the cycle well enough to bring new ideas in at the right time. Government can help make this easier, by removing impediments to the transfer of technology from government-supported labs, and universities can structure cooperative research programs to mesh with industry needs.[21] But the main task of bringing the results of research to industry lies with a company's own engineers. Encouraging their engineers to attend professional meetings, read the literature, keep in touch with research in government and university labs, and learn about their competitors' products are necessary steps for companies that mean to keep up with the competition. Most big Japanese companies do it. So do many U.S. firms. Still, many U.S. firms regard outside activities for engineers as indulgences that might advance the engineer's own professional career but are of little direct benefit to the company.

Staying abreast of technology advance means keeping up with developments abroad as well as at home. In the past, U.S. manufacturers were good collectors of technical information from other countries and good imitators of new products and processes invented elsewhere. They had to be. Only after World War II did the United States become so pre-eminent in scientific research, and U.S. technology pre-war was by no means superior to that of other countries. Yet our dominance in manufacturing was established early in the 20th century, when the majority of scientific discoveries and a great many technological advances based upon them were still being made in Europe.[22]

In the postwar period, American industry has continued to adopt and develop commercial technologies of foreign origin (e.g., the jet engine, polyester fibers, the CAT scanner), but in some cases adoption by U.S. producers has been years behind the competition (e.g., radial tires and anti-skid braking systems for automobiles). A special problem is inattention to technologies from Japan. As the Japanese concentrate more and more on leading technology advances, rather than following and improving on what others have done, Japan's importance as a source of innovation is rising fast.

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20 Gomory, op. cit., p. 14.

21 See ch. 7 for a discussion of how R&D results from Federal laboratories and government-supported university research might be more effectively transferred to private industry.

22 As early as the 1880s, U.S. manufacturing had already begun its rise to dominance, in part because the continental scale of the market allowed U.S. manufacturers to benefit from economies of scale and learning curve effects earlier than the Europeans. By the 1920s, the United States produced twice as much steel and electricity per capita as Europe's leading industrial powers, Britain, France, and Germany.

Interest in technology transfer from Japan to the United States is growing. Several public and private programs encourage U.S. scientists and engineers to learn Japanese, work in Japanese labs, and follow the Japanese technical literature. But the results of these programs are still modest. Most of the technology flow still runs the other way.[23]

TECHNOLOGY DIFFUSION TO SMALL FIRMS

Technological sophistication in small American manufacturing firms runs the gamut. Firms at the frontier of new technologies often start small; the Silicon Valley computer company that started in somebody's garage is legendary. On the other hand, the ranks of small manufacturing firms are also filled with shops that make humbler items. Significantly, small companies are suppliers of thousands of parts and components for major manufactured products that are leading items in the U.S. market and world trade (e.g., cars, computers, farm and factory machinery, medical instruments). The cost, quality, and prompt delivery of these supplies are key factors in the Nation's manufacturing performance. The level of technology in small American manufacturing firms-in product design, production equipment, organization of work, training and use of workers—is highly uneven. But technological backwardness is common enough to be a real drag on U.S. competitiveness.

For many small companies, the bedrock of technological competence is having up-to-date production equipment. It is not always easy for small firms in the United States to decide what equipment best fits their needs, or how to use it efficiently .24 Added to that are difficulties in financing; getting funds for the purchase of new equipment is usually harder for small fins, even creditworthy ones, than for larger ones, and it costs more.

More important than simple possession of advanced equipment is an educated grasp of how to use it. For example, staff members of several State industrial extension services report that small companies fairly often buy computerized equipment without fully understanding the training that workers-and managers as well—need in order to use the equipment; then, they often do not know where to turn to get the training. 25 Note also the studies mentioned above that compared German and British metalworking plants and found productivity much higher in the German factories. The difference was not in the age or sophistication of machines, which were much alike in both places, but in training.

As noted, NC machine tools are about as common in U.S. metalworking plants as in Japanese; and in both countries, small to medium-size plants (50 to 500 employees) have about the same proportion of NC machines as larger ones—11 to 13 percent of all the machine tools used in the shop (table 6-2). But in using the machinery effectively-especially in applying the soft technologies that involve organization of work and use of people—small Japanese firms seem to outperform American firms, at least in the flagship industries that have led Japan's economic growth and export success. An example is in the motor vehicle industry. Many U.S. suppliers of parts and components have not been able to meet the standards demanded by Japanese-owned auto companies operating in the United States. The small to mid-size U.S. companies that have established themselves as suppliers to the Japanese transplants have usually required months or years of training in Japanese methods (mostly soft technologies) before they could match the cost, quality, and delivery times of their Japanese competitors.[26]

Further evidence of the importance of things other than hardware to the performance of small manufacturing firms comes from Tokyo's Ota Ward, famous for its thousands of innovative small factories (of about 9,000 plants, 95 percent have 30 or fewer employees). Only about one-third of the metalworking firms responding to a 1988 survey had even one NC machine.[27] Evidently, most of Ota-ku's very small firms still rely more on their traditional

23For discussion of programs to encourage technology transfer to the United States from Japan, see ch. 7.

24For a description of some of the problems small companies face in getting advice from consulting firms, see ch. 7.

25In the past few years, a growing number of States have established programs to extend technical assistance and information to smaller manufacturing fins. OTA examined five of these programs in visits and interviews in 1988, as discussed in ch. 7. Findings from this examination also appear in Philip Shapira, "Industrial Extension: Learning from Experience, " contractor report to the Office of Technology Assessment, November 1988.

26See the brief account below of the training of North American suppliers for NUMMI, the Toyota—GM joint venture.

27Of 464 metal machining fires responding t. the survey, 150 (32.3 percent) said they had at least one NC/CNC machine tool. This was up from 18 percent in 1981, 22 percent in 1983, and 29 percent in 1986. Whittaker, op. cit.

strengths of flexibility, quick response to customers' needs, and worker skills than on advanced equipment.

The situation in Japan seems to be changing. Traditionally, Japan's smallest fins-especially those in sectors with no direct connection to the leading growth-and-export industries--have been backward. Many of the tiny "street-corner factories' in Japan are still quite primitive, with no heat, no indoor toilets, and only the simplest equipment. However, purchase and sales data collected by the Japan Machine Tool Builders' Association (JMTBA) suggest that small plants have recently kept up with their bigger brothers in purchases of computerized equipment. According to the MITI survey of establishments with more than 50 employees, 32 percent of machine tools bought in the 3 years 1985-87 were NC. In the same 3 years, the JMTBA figures show that 35 percent of *all the* machine tools sold domestically to *all sizes* of firms (including those with fewer than 50 employees) were NC.[28]

Anecdotal evidence also indicates that a wide range of up-to-date equipment can now be found in many small family-run factories in Japan. For example, one investigator who interviewed more than 100 small automotive subcontractors in Japan in 1986 reported that many were heavily equipped with advanced technologies, including NC machines, laser machines, robots, and computer-aided design. He described several scenes like this one:

> In one second-tier subcontractor of Isuzu I saw eight NC lathes, of which four were fed by robots. The rest were minded by two skilled workers, two semi-skilled workers and a part-time worker. The firm was being run by an entrepreneur whose wife was working as receptionist, secretary, finance manager and "Jack of all trades. " These were the entire personnel of the firm![29]

The success of small and medium-size Japanese manufacturing firms in the soft technologies and their recent rapid advances in installing up-to-date equipment owe a great deal to a web of supporting institutions, public and private. These include the transmittal of new technologies by major manufacturers to suppliers and a broad range of government programs for all small and medium-size manufacturers. These forms of technology transfer are uncommon, incomplete, or missing in the United States.

Major Companies and Their Suppliers

One of the many strong points of close, collaborative, long-term relations between lead manufacturers and their parts and components suppliers is that they favor transfer of technical know-how from the lead company down the supplier chain to medium-size and smaller companies.[30] In Japan, major companies often lend engineers and technicians to their first tier suppliers to help them learn how to use new equipment or arrange work more efficiently. It is also quite common for parent companies to advance funds to their subcontractors for operating costs+ specially in cases where the subcontractor's sales to tile parent company are expanding, but the subcontractor has to pay his own suppliers before he finishes work on the product, delivers it to the parent company, and receives payment.[31]

Sometimes parent companies help suppliers obtain financing for capital investment as well, but this practice is less common than in the past.[32] Japan today has so much investment capital that banks are aggressively looking for business among small and mid-size firms, since larger ones are able to meet most of their capital needs from retained earnings. However, small companies applying for a bank loan often find it is still a help if they are stable suppliers to a large, famous company.

[28] Japan Machine Tool *Builders' Association, Machine Tool Industry, Japan 1988* (Tokyo, The Association, 1988). The domestic sales figures are derived from figures on production, less exports, plus imports, omitting the category "Other Machine Tools"; they are in numbers of machine tools, not value. The JMTBA figures show that NC/CNC machines accounted for 36 percent of all Japanese domestic machine tool sales in 1985, 39 percent in 1986, and 30 percent in 1987.

[29] Toshihiro Nishiguchi, "Competing Systems of Automotive Components Supply: An Examination of the Japanese 'Clustered Control' Model and the 'Alps' Structure," paper prepared for the International Motor Vehicles program (Cambridge, MA: Massachusetts Institute of Technology, May 1987), p. 22.

[30] See ch. 5 for further discussion of how major Japanese manufacturers transfer technology to their suppliers.

[31] Yoshitaka Kurosawa, Japanese Development Bank and John F. Kennedy School of Government, Harvard University, personnal communication, Sept. 7, 1989.

[32] Toyota spokesmen, for example, told OTA in 1989 that financial aid plays no part in their close relations with suppliers; they concentrate entirely on technical advice.

Technical assistance remains a prominent feature in the relation of major Japanese firms to their suppliers. For example, Toyota's principles are to select good companies to begin with, communicate with them often from the very beginning of the relationship, and give technical assistance as often as needed to help the suppliers meet Toyota's unbending requirements for low cost, high quality, and prompt delivery. The suppliers must take an active part in raising their own standards. They know their problems better than anyone else, and must be involved in the solutions.

That the Toyota system of technology transfer to suppliers is no fluke, but is characteristic of Japanese manufacturers, was shown in a 1984 survey of manufacturing subcontractors, done by the Small and Medium Size Enterprise Agency *(chusho kigyo cho)* of MITI. Some 45 percent of respondents said they received technical assistance from a parent company, 37 percent received information, 28 percent were loaned or leased equipment, 24 percent got training for their employees, and 14 percent received financial assistance.[33] Moreover, 39 percent of respondents said they introduced new technology at the urging of parent companies (77 percent said the reason was to raise their technological level).[34]

In their survey of computerized automation in U.S. manufacturing, Kelley and Brooks found that close links between supplier firms and their customers, of a kind that would help or spur the suppliers to adopt computerized machinery, were not common in America.[35] But in the infrequent cases where such links existed, they made a difference. Only 3 percent of suppliers got any financial help from customers in buying new equipment; just 9 percent reported that their customers requested or required the use of computerized machinery. However, 20 percent of supplier firms said that customer firms had loaned engineering or programming staff. This kind of exchange was linked with a higher probability of having at least one computer-controlled machine in the supplier firm, suggesting that the loan of technical people from a customer firm to a supplier is an important conduit in the transfer of up-to-date technology.[36]

As noted earlier, the joint Toyota-GM venture, New United Motor Manufacturing, Inc. (NUMMI), is an outstanding U.S. example of technology transfer from a lead manufacturer to suppliers. After 4 years of interaction with NUMMI engineers, North American suppliers of parts and components for the autos assembled in NUMMI's Fremont, CA plant were able to match Japanese suppliers in cost, quality, and delivery time.[37] The NUMMI case exemplifies technology transfer not only from auto assembler to supplier, but also from Japan to the United States.

In Japan, the vertical transfer of technology sometimes develops to such a point that suppliers take over major functions formerly performed by the lead manufacturer. For example, both Toyota and Nissan have totally delegated assembly of some of their cars to companies that were formerly suppliers of major components. This strategy *(itaku seisan,* or consignment manufacture) enables the lead manufacturer to concentrate on high-volume production of a relatively small number of platforms,[38] while spinning off to its deputies the production of cars that are low or fluctuating in volume. In the Toyota group, for instance, Kanto Auto Works produces three different platforms on one assembly line; namely, the high-volume Corolla, the luxury passenger car Mark II, and the low-volume sports car MR2. Thus, Toyota exploits the economies of high-volume mass production in its home factory, while preserving the flexibility to make a varied range of products in the factories of its consigned assembiers.[39]

[33] Whittaker, op. cit., p. 23, citing Chusho kigyo cho (Small and Medium Size Enterprise Agency) cd., *Chusho kigyo hakusho* (SME White Paper) (Tokyo: Okurasho insatsu kyoku, 1985).

[34] Ibid.

[35] Kelley and Brooks, *The State of Computerized Automaton (1988)* op. *cit.*

[36] The probability of a supplier's adopting computer-controlled machinery with no technical support from customers was estimated at 0.49; with customer-provided technical support, the probability rose to 0.58—about 20 percent higher.

[37] In this case, much of the technology transferred was soft. Suppliers learned to apply Toyota's lean production system, with its emphasis on teamwork, training, and getting it right the first time, rather than relying on a cushion of big inventories of parts and work-in-process, to compensate for late deliveries and poor quality.

[38] A "platform" refers to all cars produced on the same wheelbase; one platform may include several different models-cars with different sheet metal skins and interiors.

[39] Nishiguchi, Op. cit., pp. 10-12.

Companies farther down the chain of suppliers sometimes employ a similar strategy of first transferring technology to the level below them, and then turning over major tasks to their feeder fins. Not infrequently, talented employees of small third or fourth tier companies leave to form their own companies, but they still maintain close ties with their former bosses, working for them as sub-subcontractors. The ex-employers consider this hiving off natural, and often help out the new firm with technical assistance, sometimes even financing.[40] In their view, skilled, enterprising workers are likely to be more productive when working for themselves than when working for somebody else, especially in a small family-run firm where advancement possibilities are limited.

Nishiguchi offers the example of a subcontractor who specialized in prototype manufacture for the electrical, motor vehicle, and precision instrument industries. His strong suit was meeting short deadlines; for this he could command premium prices. He furnished his own factory with a facsimile machine and such up-to-date equipment as CAD/CAM systems, laser milling machines, and CNC machines, and he cross-trained his workers on several kinds of equipment. Beyond this, he set up an ''educational factory" nearby, where he trained selected workers, lent them money to buy machines and, after a year or two of training, provided financing for them to set up their own businesses, attached to the mother firm. In 1986, when Nishiguchi interviewed him, this man had a network of 62 subcontractors-all equipped with advanced machinery-30 of whom had been incubated at his firm. When he received a rush order on his facsimile machine, he could spread the work out among his own employees and his subcontractors, and often deliver the order within hours.[41] The result of such ties between patron companies and suppliers is superior flexibility, combined with advanced technology.

Japanese Government Programs for Small and Medium-Size Firms

In Japan's combined public-private support system for small and medium-size manufacturing fins, the government role is pervasive.[42] Spending and loans by the national government for help to all small business (including non-manufacturing) amounted to about 4.4 trillion yen in 1989, or $31.2 billion at 140 yen to the dollar. Of this, only $1.4 billion appeared in the regular general account budget, which is supported directly by taxes. The rest, $29.8 billion, was in the Fiscal Investment and Loan Program, a capital budget often called the second budget, which derives its revenues from government trust funds and the country's huge, government-subsidized postal savings program.[43] Altogether, spending for small business programs amounted in 1989 to nearly 5 percent of the total regular and capital budgets of the national government.[44] This sum does not include spending by prefectures, cities, and city wards, which also contribute handsomely to programs for small businesses, matching the national government's contribution in some cases.[45]

Modernization of small firms has long been a concern of the Japanese Government; some loan programs targeted to small businesses date back more than 20 years. Reasons for the focus on small and medium enterprises (SMEs) are social and political as well as economic. SMEs play a very big part in the Japanese economy. In 1986, in the manufacturing sector alone, SMEs (300 or fewer regular employees, and capitalized at 100 million

40Ken-ichi Imai, Ikujiro Nonaka, and Hirotaka Takeuchi, ''Managing the New Product Development Process: How Japanese Companies Learn and Unlearn," in Kim B. Clark, Robert H. Hayes, and Christopher Lorenz, *The Uneasy Alliance: Managing the Productivity-Technology Dilemma* (Boston, MA: Harvard Business School Press, 1985), pp. 365-366; also, Mari Sake, "Neither Markets nor Hierarchies: A Comparative Study of Informal Networks in the Printed Circuit Board Industry,' Lecturer, Industrial Relations Department, London School of Economics and Political Science, mimeo, May 1988.

41 Nishiguchi, Op. Cit., pp. 23-24.

42The material in this section is drawn mostly from D.H. Whittaker, "New Technology Acquisition in Small Japanese Enterprises: Government Assistance and Private Initiative,' contract report to the Office of Technology Assessment, May 1989; and from OTA interviews in Japan in March 1989. Yoshitaka Kurosawa, on leave to Harvard University from the Japanese Development Bank, contributed additional information in a letter to Julie Fox Gorte, OTA project Director, dated Sept. 7, 1989.

43The main government subsidy for postal savings is in the form of a tax exemption for interest. Also, during the many years that Japanese financial institutions were strictly regulated, the interest rate on postal savings was higher than for time deposits elsewhere.

44In fiscal year 1989, the total budget of the Japanese national government was 92.7 trillion yen ($662 billion), including 60.4 trillion yen in the general account, and 32.3 trillion yen in the Fiscal Investment and Loan Program. Japan Economic Institute, *JEI Report*, May 12, 1989.

45For example, in fiscal year 1988, the prefectures matched the national government's provision of 2 billion yen ($154 million) fOr the Equipment Modernization Loan System and the Equipment Leasing System for smaller enterprises.

yen or less) represented 99.5 percent of establishments, 74.4 percent of employees, and 56.5 percent of value added.[46] At the same time, wages in these small manufacturing firms are at least 25 percent lower than in the major companies, working conditions are frequently dismal, and technologies have often lagged behind the leaders. Besides these reasons for government concern, there is the political fact that small business has been a steadfast, strong supporter of the ruling Liberal Democratic Party. Every election brings new pledges of measures to improve the climate for small business.

The Japanese national programs for SMEs include both financial and technical assistance, and the two are intertwined. In the 1980s, special attention has been given to programs aimed to help small business adopt high-tech equipment such as computerized machinery and robots. Some key assistance programs that encourage purchase of advanced equipment are open only to still smaller firms, with no more than 20 to 100 employees.[47]

Among the multiple services the government offers SMEs are a big program of direct loans for operating funds or plant and equipment investment and a still bigger program of government guaranteed loans. Other services include: a system to lease new equipment to SMEs on generous terms or sell it on the installment plan; loans to groups or cooperatives of SMEs; management analysis for individual firms —a condition for government loan approval; public testing and research centers, where SMEs can use expensive equipment for a nominal fee and can consult with engineers on technical problems. SMEs also get tax breaks for investment in new equipment, especially high-tech equipment. For example, a 1984 law allows SMEs the option of taking a special first year depreciation of 30 percent for investments in electronic and ‘‘mechatronic’ technology, which includes NC machine tools, computers, and robots.

The national government, mainly through MITI and the Ministry of Finance, is the grand overseer of the SME programs and is the top provider of funds. The actual dealings with business people fall to the prefectural and local governments, and to quasi-public organizations such as chambers of commerce (in cities, or “societies of commerce and industry” in towns and rural places) and federations of small business associations.

In 1987, loans to SMEs via the three main government financing institutions amounted to 3.8 trillion yen, or $27 billion.[48] Japanese loan guarantee programs for SMEs are still larger. The 52 nation-wide credit guarantee associations underwrote 7.8 trillion yen ($56 billion) in loans to SMEs in 1987. By way of comparison, U.S. small businesses (up to 500 employees) got $47.3 million in direct loans from the Small Business Administration in fiscal year 1989, and loans were restricted to special disadvantaged groups. Federally guaranteed loans are available more generally to U.S. small businesses; they amounted to $3.6 billion in 1989. These figures are only illustrative; they do not include, for either country, financial aid available from State (or prefectural) and local governments. And, to put the comparison in perspective, small businesses play a bigger part in Japan than in the United States. Even considering the larger size of the U.S. economy, small and medium-size manufacturing firms are more numerous and employ more people (10.7 million v. 6.8 million) in Japan than in the United States. Finally, keep in mind that these figures for government loans and loan guarantees are for all small businesses in both countries, not just for manufacturing firms. With all this, it is still notable that the Japanese Government provides about 20 times more financial aid to small business than the U.S. Government does.

Even so, government financing is not as important to Japan’s SMEs as it was just a few years ago. (Box

[46] By comparison, in the United States in 1986, small businesses (enterprises with fewer than 500 employees) represented 85 percent of manufacturing establishments, 35 percent of employment, and 21 percent of value added. An establishment is a single physical location where business is conducted. An enterprise is a business organization consisting of one or more establishments under the same ownership or control. *The State of Small Business: A Report of the* President transmitted to the Congress, 1989 (Washington, DC: U.S. Government Printing Office, 1989), p. 21; table 13, p. 21; table A. 15, pp. 80-81; table A.20, pp. 92-93.

[47] Japanese firms with fewer than 100 employees constitute 97 percent of establishments, 55 percent of employment, and 39 percent of value added in private manufacturing in Japan; comparable figures for firms with fewer than 20 employees are 87 percent of establishments, 29 percent of employees, and 15 percent of value added.

[48] This figure is net of repayments; it includes 1.80 trillion yen from the chushokigyokinyu (Small Business Finance Corporation), 1.85 trillion yen from the kokumin kinyu koko (Peoples’ Finance Corporation) and 128 billion yen from the shoko chukin (which is not always included in the group of government financial institutions because it raises part of its funds from association members). The gross amount of loans made to SMEs in 1987 by these three institutions was 5.6 trillion yen—2.26 trillion, 2.89 trillion, and 493 billion yen respectively.

6-A offers a Yokohama factory owner's account of his "graduation" from government financing and technology transfer programs over the years.) In the late 1980s, with the quick recovery from the rise of the yen and the great prosperity that followed, Japan was awash in capital. The august city banks, which once gave most of their attention and funds to large companies, were now scrambling to do business with SMEs. In March 1981, for example, 25 percent of city bank loans went to SMEs, but by August 1988 the figure was 64 percent. Even though the government loans are usually pegged at lower rates-e. g., 4 percent instead of 5 percent to individual firms in 1989, as low as 2.7 percent when provided through cooperative associations, and zero for the government's half share of certain equipment modernization loans-companies often prefer the greater simplicity of dealing with a bank.

Government loans are still an essential source of financing for small startup companies with no track record, for firms changing direction, and as a safety net in times of adversity. For example, many of the 9,000-odd small manufacturers in the Ota ward of Tokyo were hard hit by the yen's rise in 1986-87. In those 2 years, Ota-ku's firms borrowed 1.5 billion yen ($11.5 million) in emergency loans to cover operating costs. But the overall trend in the late 1980s was for private loans to edge out government financing. Government loans dropped from 13 percent of all outstanding loans to SMEs in 1980 to 9 percent in 1988. These figures understate the government role in financing of SMEs, however, because they omit the system of loan guarantees. And despite the decline of Japanese Government financing for SMEs, the volume remains huge in U.S. terms.

Besides its big, general program of direct loans available to all SMEs, the Japanese national government offers a whole menu of SME ''measures,' funded at about 225 billion yen ($1.6 billion) in 1987. Among these are two special programs designed specifically to encourage SMEs to acquire modern technology. One of these, the Equipment Modernization Loan System, made 6,000 loans in 1987, totaling 41 billion yen ($293 million) in 1987. The program is open only to firms with 100 or fewer employees, as shown in table 6-4. It provides up to half the amount of the funds needed for the modernization project; notably, that half is interest free. According to officials of MITI's Small and Medium Enterprise Agency, no collateral is required for these government loans because commercial banks can provide loans requiring collateral.[49]

The Equipment Leasing System, through which firms can lease new equipment or buy it on the installment plan, is another key technology-promoting measure. Nothing better illustrates the Japanese policy of fusing financial assistance with promotion of technological advance than this program. Founded in 1966 and open only to firms with 20 or fewer employees, its direct purpose is to help small, struggling companies invest in new equipment at affordable terms (easier terms than those offered by private leasing companies, and easier even than the Equipment Modernization Loan System). The system has the added effect of providing a quite substantial, assured market for producers of capital equipment suitable for small shops, especially machine tools. A high-tech equipment and machinery leasing system, added in 1986, is open to firms with as many as 80 employees, giving added support to the market for such things as NC machine tools, robots, and computers. In 1987, about 4,500 leases or installment purchases, amounting to 49 billion yen ($350 million) were made under this program. About one-third of the loans and leases went to SMEs producing machinery and other metal goods, mostly for buying or leasing NC machines.[50]

In this connection, it should be noted that the government is also a partner in quasi-private leasing companies that serve large as well as small companies. For example, the Japan Electric Computer Corporation (JECC), founded in 1961 to buy computers and lease them to users at subsidized rates, got half its capital from the Japan Development Bank, a government institution. The similar Japan Robot Leasing Company (JAROL) was founded in 1979, with 60 percent of its capital coming from the Japan Development Bank. In addition, in 1980 the Small Business Finance Corporation allocated funds specifically for loans to small businesses buying robots.[51] The existence of these leasing and loan

[49]OTA interview with Kazuhiko Bando and Kazumi Suda, Small and Medium Enterprise Agency (*chusho kigyo cho*), MITI, Mar. 16, 1989.

[50]In Tokyo, 37 percent of the loans made under the Equipment Modernization program in 1987 were for buying CNC machines. (Tokyo Metropolitan Government Labour Economics Office, untitled mimeo, 1989, cited in D.H. Whittaker, op. cit.)

[51]Ezra Vogel, Comeback (New York, NY: Simon & Schuster, 1985), pp. 90, 122-123.

Box 6-A—A Small Plant in Yokohama

Showa Precision Tools Co., Ltd., of Yokohama, Japan makes plastic processing dies, blanking dies, progressive dies, and measuring and testing equipment.[1] The company's name is well chosen. Everything about its newly built factory in Kanazawa Industrial Park speaks of precision, from the understated architecture of the front office to the neatly pressed company uniforms worn by the company president and founder, Mr. Masanari Kida, and his chief engineer, Mr. Y. Yokoyama. Showa tools are esteemed for their quality and design. Because of that reputation, the company is prospering. The first sentence in the company outline booklet says, "We are enjoying a convenient life, thanks to the tools and machinery which have been developed. "

Although Showa provides all its own capital now, Mr. Kida is well acquainted with Japanese Government programs that offer financing for small and medium enterprises. Showa made frequent use of them from the time it was founded 30 years ago until about 10 years ago. Even more recently, when Showa built a new factory in Kanazawa Industrial Park, government financing filled a gap. Mr. Kida had the proceeds from the sale of his old factory and a substantial loan from a bank, but was still short of what he needed for new machinery. Financing from the government's small and medium enterprise program made up the difference.

Although government financing is cheaper than a bank loan—the difference is a percentage point or so, or about 4 percent instead of 5 percent-going through government programs is a hassle, Mr. Kida said. "If I go to the bank, I can get the money today," he explained. "If I borrow from a government program, it takes a month, and I have to fill out a lot of forms. This hassle is still worth it, he believes, for brand new businesses that have no track record or an established relationship with a bank. Indeed, government financing was essential for Showa in its earlier years.

One part of the government program is still useful to Showa———technical advice. When Mr. Kida last used government financing, advisors from the guidance center in the Yokohama city office gave him an analysis of his financial arrangements. At his request, an advisor also evaluated some of his plans for new machine purchases. His relationship with that advisor has lasted to the present day through the city's yearly management service, which provides technical information and evaluation to small and medium-size firms. In return, the advisor uses the information he gets about the firm to enlarge his understanding of technology use and other conditions of small businesses. The service also gives Mr. Kida general information on what his competitors are doing.

Firms like Showa can also get some training from the Yokohama city office. On request, the office will send a sensei (teacher, or master) to train the employees total quality control techniques. This training is fairly extensive. Between June and October 1988, the *sensei came* to Showa for eight 2-hour sessions to train 14 group leaders (these are quality circle group leaders, not necessarily the formal authority figures). The ***sensei*** brings written materials **to every** class, and then the group leaders are responsible for teaching the other people in the-group. The lessons were:

- What Are Small Group Activities?
- Why Are Group Activities Necessary?
- Small Group Activities and Total Quality Control
- What Is Quality?
- How To Introduce Small Group Activities
- Let's Master Quality Control Methods
- The Way of Leadership
- How To Succeed in Small Group Activities

The lessons do not accomplish miracles. Although the classes may get the group leaders ail fired up, other workers are not always so enthusiastic. However, the group leaders do impart to others in the group what they learn, and eventually the lessons of Total Quality Control are learned by all. Mr. Kida did not think the services offered by Yokohama prefecture were unique. He admitted that Yokohama and Kanagawa were more positive about such activities than other prefectures-but only a bit more.

[1]Information for this box comes from interviews conducted by OTA staff in Yokohama, March 1989.

Despite its present independence from government financing, Showa is still part of a government-supported cooperative association for small companies. Members can get up to 65 percent of their investment costs from the small and medium enterprise public corporation, at 2.7 percent interest. The maximum term of such loans is 15 years, and the money is provided for additions to plant and equipment. The preferential financing is a strong incentive to join a cooperative association. There is also a down side to joining. Money borrowed as a group has to be repaid as a group, so if one member fails or gets into trouble, all the other members are responsible for his debts and his recovery. Also, the land belongs to the group, and every inch of the precious stuff is used. So, if a company wants to expand, it can do so only if someone else in the group goes under and their land becomes available, and even then approval of the group is needed. Others may want to expand, too.

In response to questions about the drive to innovate in small fins, Mr. Kida's unhesitating answer was competition. 'You must innovate or you get beaten,' he said. Since 1986, Showa has bought 11 new NC machines. and now about 70 percent of all his machines are NC. He never leases the machines, on principle, because leasing costs a bit more than buying. However, companies that can't secure the capital up front need to be able to lease machines. Like government financing programs, leasing is a nice option for fledgling companies.

Mr. Kida has an extra incentive to be right at the cutting edge of new technology. His business is an independent one, not in anyone's supplier group or *keiretsu*. Companies in cooperative associations tend toward being more independent, according to Mr. Kida. Many firms would like to be on their own, but it is harder than being somebody's supplier. ''If you want to be independent, you have to study unceasingly,' he says. He gets no technical advice from his customers, although engineers do come from customer companies to discuss their technical requirements. He has never gotten any financial assistance from a customer, either. But even in companies that are in a supplier group, the parent companies are giving less advice and less financing than they used to, perhaps because it isn't necessary, and perhaps&cause of other changes in the environment of large companies—-moving offshore, for example.

Finally, Mr. Kida was asked why he didn't just sell up. "You could be a millionaire, and live anywhere you wanted," said the interviewer. "You could buy a *ramen* (noodle) shop, and stop the struggle. " Mr. Kida seemed speechless at the thought, so Mr. Yokoyama, the chief engineer, answered. He was horrified at the suggestion. "We have 100 employees here," he said earnestly, "and they have families. That's 400 people. We're responsible for those people. What would they do if the owner bought a ***ramen*** shop? Where would they go? No, we have to stay in business. Four hundred people depend on this business. '

Table &4-Japanese Government Equipment Modernization Loan and Equipment Leasing Systems for Small and Medium Enterprises

	Equipment modernization loans system	Equipment leasing system: Equipment leasing (installment plan): General equipment	Equipment leasing system: Equipment leasing (installment plan): High-tech, information processing equipment	Equipment leasing system: Equipment leasing: High-tech, information processing equipment
Main recipients	Small and medium enterprises with 100 or less employees	Small and medium enterprises with up to *20* employees	Small and medium enterprises with up to 80 employees	Small and medium enterprises with up to 80 employees
Maximum amount of loan or value of leased equipment	Half of funds required up to 30 million yen	Equipment worth up to 25 million yen	Equipment worth up to 50 million yen	Equipment worth up to 50 million yen
Interest or charge	Free	4.5% of the cost of equipment as per annum charge (an additional 1 0°/0 guarantee money is required)	4.5% of the cost of equipment as per annum charge (an additional 10% guarantee money is required)	About 7°% as per annum charge (including tax and insurance premium)
Period	5 years with l-year grace period	4 years and 6 months (11 years and 6 months for anti-pollution equipment)	6 years and 6 months(11 years and 6 months for anti-pollution equipment)	Up to 7 years (84 months)

SOURCE: Ministry of International Trade and Industry, Small and Medium Enterprise Agency (*chusho kigyo cho*) SMEA mimeograph, 198 (untitled)

programs assured equipment producers of a solid market, which probably encouraged them to gear up for expanded output-even though, as it turned out, not all the programs were heavily used. For example, purchases of robots by Japanese firms turned out to be so great that JAROL leased only 790 units in 1982, when shipments were almost 10,000.[52]

Still other national government "special measures" are designed to help bring SMEs up to speed technologically. According to MITI officials, the SME programs were originally formed with the view that small companies needed information more than financing. To get public financing under some programs, firms must have a management analysis, paid for by government funds and provided free by local governments, associations of commerce, or federations of small business associations. Often the analyses focus on finance, sales, and marketing, but advice on technology and production methods is also given. As illustrated by Mr. Kida's experience (box 6-A), small businessmen may form a lasting relationship with the person who does the original analysis for the loan, often coming back repeatedly for consultation on technical or other business matters.

Public testing and research centers also play a big part in technology diffusion, Japan had 185 of these centers in 1985, with 7,000 employees and an annual budget of 66 billion yen (about $470 million), half from the national budget and half from the prefectures. SMEs can come here and, for a small fee, use inspection equipment that is too costly or used too seldom to make purchase worthwhile. They can also find consulting engineers for research and advice on special problems, and they can bring the consultants to their own factories if necessary.

Local technology demonstration centers supplement the national testing and research centers. The industrial hall in Tokyo's Ota ward is a good example. Advisors at the hall have regular consultation hours for the Ota-ku's thousands of tiny businesses—Tuesday, Thursday, and Saturday, from 10 to 4, on mechanical matters, and the alternate weekdays on electrical matters. The hall has about 500 consultation meetings a year in seven areas. In order of popularity, they are: machines, measuring devices, materials, machining process, electrical problems, controllers, and a miscellaneous category including legal problems. An example of an electrical problem: there are frequent, unpredictable daily fluctuations in the voltage delivered by the city. Small businesses need to learn how to cope with the fluctuations and how to make machinery last in spite of them. According to the managers of the hall, small firms could figure out many of these problems themselves, but they don't have time.

Besides these regular consultations at the hall, which are free, firms may ask advisors to visit their plants for a fee of 10,000 to 20,000 yen a day (about ***$70 to $140).*** For knottier problems, firms may be referred to the Technology Experimental Center in metropolitan Tokyo, which has about 160 highly qualified consultants—30 in technical fields—and 200 technical advisors (this is one of the 185 national public testing and research centers). Another service the Ota industrial hall offers is use of specialized measuring and calibrating machines, at a fee of about $4 for half a day. In addition to all this, the hall puts on exhibitions three times a year showing machines made in the wards to buyers in the area. Sometimes buyers from other countries are invited as well. Occasionally, the prefecture exhibits Ota-made machinery at shows in other places.

According to surveys of small businesses, public programs rank low on the list behind parent companies and machine and equipment makers as sources of technical information. This is no reflection on the public programs; services like those at Ota-ku's industrial hall are used by SMEs and seem to be well regarded.[53] It is more an indication that the level of technology diffusion to SMEs in Japan, including the active role taken by parent companies, is extremely high. The role of parent companies may be diminishing a bit, however, as the bonds between parent companies and subcontractors are weakening somewhat, The reasons are first, that major firms are doing more subcontracting offshore; and second, that small supplier firms, more prosperous than ever

[52]Kenneth Flamm, "Changing Pattern of Industrial Robot Use, " in Richard M, Cyert and David C. Mowery (eds.), *The Impact of Technological Change on Employment and Economic Growth* (Cambridge, MA: Ballinger Publishing Co., 1988), p. 299. According to Vogel (op. cit.) virtually no robots were exported from Japan in the early 1980s because domestic demand was so great.

[53]The small business owners interviewed by OTA staff in Japan spoke favorably about government technical assistance. One, who said he generally prefers his own resources to government programs (though he had taken a large government loan to finance a new building for his factory), had no reservation in praising the Tokyo technology center. He goes (here about once a month for testing of materials and inspection services. The service is cheap-about 3,000 yen per visit—and the consulting engineer is very kindly and knowledgeable (''a good study person' '),

before, are able to be more independent. In Ota-ku, officials say, about 1,000 of the 9,000 manufacturing firms are now independent, with no strong ties to major firms. Many of these companies can make good use of public technical assistance. The government is encouraging small independent firms to form cooperative associations, to work together on R&D and share technical, management, and marketing information among themselves (see the discussion below on horizontal links between small firms).

Government programs offer specific help to startups, in addition to loans. An example of public-private partnership to encourage high-tech startups is the Kanagawa Science Park (near Yokohama). Building began in 1989. When completed, it will provide common research facilities, including precision measuring and calibrating equipment, plus the usual business incubator services such as accounting and payroll. It is intended to be a communications center as well, the hub of an electronic information network that will extend to many businesses in the prefecture. Finally, there are plans to make the Science Park an international convention center--complete with hotels, banks, and restaurants-designed especially to serve resident companies. The Science Park is set up as a stock company, with construction and initial subscriptions financed by funds from the Yokohama Bank and the Kanagawa prefecture. Other prefectures are planning similar schemes, but Kanagawa is the first to take action.

To sum up, financing new technologies seems to be no big problem for Japanese SMEs, and the abundance of government assistance is surely one reason. Where small U.S. firms may find the availability of capital a real barrier to investing in modern equipment (e.g., a CNC machine tool), their Japanese competitors can turn their attention to whether the equipment precisely fits their needs, whether it is better to buy it or lease it, and whether getting a 4 percent loan from the government rather than a 5 percent loan from the bank is worth the bother of waiting a month instead of a day. In addition, technical assistance is very broadly available from many sources, often linked with some kind of financial assistance. Small manufacturers in the United States are not nearly so richly supplied with guidance in adopting and using new technologies.[54]

Horizontal Links Between Small Firms

Another way to promote the widespread adoption of advanced technology, down to the level of tiny family-run firms, is through horizontal networks that give member firms help in developing and acquiring new technologies, and advice on financing, management, and marketing as well. Such systems are prominent in the textile and metalworking industries of both Japan and Italy. They can be found elsewhere too, as in Denmark's textile and furniture industries. These networks involve a considerable degree of cooperation and information-sharing among competitive fins-practices that are quite foreign to U.S. business tradition. In some countries, the networks are supported by a range of government programs that are mostly missing in the United States.

A well-known example of horizontal links among small firms is in the northeast-central part of Italy, known as the Third Italy .55 Networks of small, technologically sophisticated textile and metalworking firms began to develop in this region in the late 1960s. By the early 1980s, these small enterprises were supporting a prosperous economy. In Emilia-Romagna, for instance, manufacturing wage rates in 1980 were 125 percent of the Italian average. In 1985, the region ranked second among Italy's 21 regions in per capita income, having risen from 17th in the 15 years since 1970.

The cooperative networks that were key factors in the region's economic success were founded with the help of local governments, but later on were largely financed and operated by the firms themselves. Artisans' trade associations, technical schools and universities, and labor unions have also supported the networks' programs. The networks provide technical advice on new equipment, products, and processes; financial help in acquiring new

[54] See the discussion in ch. 7.

[55] The many writings on cooperative networks in the Third Italy include Giacomo Becattini, " The Development of Light Industry in Tuscany: An Interpretation, ' *Economic Notes*, vol. 3, 1978; Sebastian Brusco, "The Emilian Model: Productive Decentralization and Social Integration," *Cambridge Journal of Economics, vol. 6, No. 2, 1982;* Michael Piore and Charles Sabel, *The Second Industrial Divide (New* York, NY: Basic Books, 1984); Edward Goodman, Julia Bamford, and Peter Saynor (eds.), *Small Firms and Industrial Districts in Italy* (London and New York: Routledge, 1989); Daniella Mazzonia and Mario Pianta, ''An Innovation Strategy for Traditional Industries: Experience of the Italian Textile Districts of Prato and Como,'' mimeo, September 1986; Robert E. Friedman, "Flexible Manufacturing Networks, ' and Richard C. Hatch, ''Learning From Italy's Industrial Renaissance," in Corporation for Enterprise Development, *Entrepreneurial Economy*, July-August 1987.

machinery and training in using it; business services such as making up payrolls and sending out bills; and advice on markets and assistance in parceling out work on large orders. Local governments, together with the artisans' trade associations, have also developed industrial parks where factory space is offered at reasonable, stable rents. The concentration of small firms in the same area carries an added bonus, making it easier for the firms to divide up large contracts or find subcontractors if they get jammed with too much work at one time.

A notable feature in the small firms that makeup these manufacturing networks is their use of advanced equipment. Part of the reason lies in the nature of the industries--cloth and clothing, shoes, furniture, metal parts for machinery or precision instruments. The investment needed for an efficient unit of production in such industries is not formidably high. A cluster of CNC machine tools or electronic sewing machines or weaving machines is not beyond the financial means of a family-run enterprise-especially when help in arranging financing is available to the small firm, as it is in this part of Italy. Loan guarantee cooperatives (established by the trade associations) may arrange preferential bank financing for buying the equipment; alternatively, members of artisans' trade association can lease machinery. Not only is the equipment affordable but objective advice on what to buy and consultation on using it is also available from Service Centers serving specific industries (organized by trade associations together with local governments, labor unions and other business groups).

Government support of the networks is mostly confined to the regional and municipal levels. The national government has had little to do with it. The distinctively Italian Eurocommunist government of Emilia-Romagna was the pioneer, but rightist regional governments, such as the Christian Democratic one in the Veneto, have also lent their support. As noted, the major contributions from the regional government were made at the beginning, in the form of financial and planning support for starting up networks.

Whether these largely voluntary horizontal networks are sturdy enough to last through changing economic conditions is an emerging question. Vertical as well as horizontal networks have always been a part of the scene in the Third Italy; many small firms are regular subcontractors for big enterprises (e.g., Benetton in apparel). However, the presence of strong horizontal networks has probably given small firms an extra measure of independence and bargaining power. Today there may be a trend toward greater dominance by lead firms. A recent study of the textile districts of Prato (in Tuscany) and Treviso (in Veneto) and the food-producing machinery sector in Emilia-Romagna found increasing top-down control.[56] The pattern is for small firms to continue decentralized production, but under the growing financial and strategic control (including the choice of technology and subcontractors) of locally dominant firms or outsider corporations.

Japan also has regional centers that are outstanding examples of network manufacturing, especially in metalworking and textiles. Sakaki Township in rural central Nagano Prefecture is one such.[57] This mountainous little community, with a population of 16,000, had 321 manufacturing enterprises in the mid- 1980s, of which 257 had fewer than 10 employees and only 4 had more than 300. Among them, these firms owned nearly 600 computer-controlled machine tools.

Sakaki's small metalworking firms began to flourish in the 1960s, at first on the basis of auto subcontracting. They have since become much more diversified, branching out into general machining, electronics, and plastics, thus escaping dependence on the extremely demanding auto industry. The financial underpinning for this growth was Japan's extensive national program of government loans and loan guarantees to small business, administered by the local association of commerce (shokokai). The *shokokai* provides technical support along with its financial aid, reviewing the plans of borrowers and often proposing specific changes. It routinely arranges classes in computer programming to supplement the basic introductory course given by the manufacturer of NC machine tools, and sometimes

[56] Bennett Harrison, ''Concentration Without Centralization: The Changing Morphology of the Small Firm Industrial Districts of the Third Italy,'' paper presented to the International Symposium on Local Employment, National Institute of Employment and Vocational Research, Tokyo, Sept. 12-14, 1989.

[57] For a detailed description of the regional metalworking industry of Sakaki Township, see David Friedman, *The Misunderstood Miracle: Industrial Development and Political Change in Japan* (Ithaca, NY and London: Cornell University Press, 1988), ch. 5.

brings in specialists to help individual companies with particular problems. In Sakaki, factory operators say that they know more about using the equipment than the large firms they supply .58

In the Japanese textile industry, big firms predominate upstream in fiber making and spinning.[59] But weaving and knitting is done mostly in small family-run firms with no more than 20 looms (usually installed in a shed or annex to the weaver's home), a few family-member workers, and two or three employees. This system of family weaving is an outgrowth of the centuries-old custom of landlords providing looms for tenant farmers to use in the winter slack season. With land reform, the tenants became owners. These tiny enterprises are well--suited to producing short runs to order—a good fit with the Japanese textile industry strategy of competing on the basis of diversity, high quality, and responsiveness to customers' needs.

Most of these small firms are part of vertical networks; they are tied to one of the great spinning companies or to trading companies that supply them with yarn, buy their cloth and, quite commonly, give them free technical advice. A second important source of technological help is the regional industry cooperatives. These are voluntary associations, funded mostly by members but aided by the many government programs for SMEs and cooperatives. Typical activities are to organize training programs in new techniques and the use of new machinery, and to help firms apply to special industry banks that serve small and medium-size firms for government guaranteed loans. Some cooperatives are more active. For example, the Nishiwaki Weaver's Cooperative, located in a rural area, owns and leases to members about 2,000 of 11,348 looms in use by the membership. Typically, the cooperative pays two-thirds of the purchase price and the weaver pays one-third, plus lease payments for the remainder. The cooperative may also guarantee loans for members who want to buy looms outright.

The state-operated system of research institutes also helps small firms keep abreast of new technologies. Japan has 46 textile research institutes in its 47 prefectures. Besides collecting industry information and providing a computer connection with the Scientific Research Center in Tokyo, the institutes conduct experiments and research for small firms, charging a fee for service. The research is directed toward practical problems (e.g., why a color may fade), rather than broader, more basic topics that would interest a university research team.

The Japanese networks, much more than the Italian, have solid, consistent support from government programs, some available both to individual small firms and associations, and some targeted only to cooperative groups. The main program targeted to groups is the SME Upgrading Capital System, administered by the Japan Small Business Corporation (JSBC).[60] It lends money to the prefectures which, in turn, add funds of their own and make loans to groups and cooperatives. Loans, for periods of 7 to 16 years, are at low interest (2.7 percent) for general activities and at zero interest for special activities. In 1987, government-supported upgrading loans to groups and cooperatives amounted to 395.3 billion yen ($2.8 billion). Another source of low-cost financing for cooperatives is the shoko chukin bank, which collects money from coop members, supplements it with government funds, and then makes loans to members. In addition, a small government program (national and prefectural) promotes joint R&D by small fins. It makes awards at the level of $2 million to $3 million yearly to a couple of dozen cooperative associations. Cooperatives can also take advantage of the free or low-cost public technology extension services.

The Japanese Government particularly encourages the formation of cooperatives in industries with many very small, weak firms. Box 6-B describes the activities of a cooperative of 18 plastic mold equipment manufacturers in and around Tokyo and Yokohama, and some of the government programs that support it.

[58] Ibid., p. 192, note 17.

[59] Main sources for this part, in addition to standard works on the world textile industries, are Ronald Dore, *Flexible Rigidities: Industrial Policy and Structural Adjustment in the Japanese Economy, 1970-1980* (Stanford, CA: Stanford University Press, 1986); and The MIT Commission on Industrial Productivity, "The U.S. Textile Industry: Challenges and Opportunities," in *The Working Papers of the MIT Commission on Industrial Productivity* (Cambridge, MA: The MIT Press, 1989), vol. 2.

[60] This program is in addition to the loan programs for individual SME firms,

Box 6-B—A Plastic Mold Equipment Cooperative in Japan

The Keihin Plastic Kanagata, or plastic mold equipment cooperative, is an association of 18 small companies in Ota-ku (a city ward in Tokyo), other places in Tokyo, and Kanagawa-ken (a prefecture near Yokohama).[1] The cooperative's modest offices are located in a compact building in a pleasant but unpretentious Tokyo neighborhood. Within this rather humble exterior is a dynamo of activity.

The Japanese die and mold industry is characterized by a great diversity of products, custom manufacturing, heavy reliance on skilled workers, and a great preponderance of small and medium-size enterprises. Nine of ten plastics toolmakers are small firms with fewer than 19 employees. This kanagata is typical: the 18 member companies are all very small, and for them the 6 million yen ($43,000) price of admission is steep.[2] The rewards for joining are large, however. Members can rely on the kanagata to collect orders from larger customer firms and apportion them to members so that all are kept busy, and customers can usually be accommodated even when business is booming. When business is slow, kanagata staff can pound the pavement in search of new orders. "We try to make sure all the members are working at full capacity, explained Mr. S. Sugano, director of the cooperative.

The kanagata also helps with purchasing, giving member firms both technical assistance in finding good equipment and quantity discounts. The discounts are not inconsequential; on some machines they are as much as 60 percent. (Discounts on quantity purchases are available not only to members of the coop but to a wider circle of 53 firms, in an organization the coop founded.) Another benefit is in machine leasing. For example, 4 years ago, the kanagata bought 24 CNC machines and leased them out to members. Altogether, the machines cost 450 million yen ($3.2 million). The kanagata used government loan programs to aid in buying them; one program provided two-thirds of the money at 2.7 percent interest over 10 years, and another provided the other one-third at 7.6 percent interest, also over 10 years.

Even with quantity discounts and leasing on favorable terms, it doesn't always pay for members to acquire their own equipment, if it is used quite infrequently. For example, a few years ago, the kanagata bought a CAD system; a member of the coop staff who formerly worked for a plastic design company trains members to use it. Another low-cost government loan, for 28 million yen ($200,000), helped the kanagata buy the equipment. Eventually, the coop wants to be able to hook up the CAD system to computer- aided manufacturing in members' plants. lt is exploiting government programs to establish computer networks to make possible the CAD-CAM connection.

In addition, the cooperative can provide both long and short term loans to member companies. Long-term loans are funneled through the kanagata from the shoko chukin bank, which collects money from coop members, adds government funds, and makes loans on favorable terms to the members. A committee of the kanagata approves the loans. Typically, long-term loans are used for operating capital. Members can also borrow up to 6 million yen ($43,000--the same as the membership fee) for 6 months at a rate of 1 percentage point above the commercial bank prime rate (about 5 percent in 1989). These short-term loans are used mainly for special purposes such as employee bonuses or debt service that firms are temporarily unable to cover (a common occurrence when firms were adjusting to the rapid rise of the yen in 1986-87). Also, members can buy insurance from the coop to cover possible losses if one of their customers goes bankrupt.

Finally, the cooperative also provides many kinds of education and information sharing services. For example, members study CAD/CAM applications together, and in 1989 the kanagata had a study group examining the implications to members of the new consumption tax.

The kanagata supports its staff and activities not only through membership fees but also by taking 1 percent of the order value of the customer orders it handles. Also, in selling equipment to members at the discount price, it adds a charge of 3 percent of the regular, undiscounted price and puts that into the coop's operating fund (which was about 600 million yen, or $4.3 million, annually in 1989).

Throughout Japan, there are about 12,000 Kanagawa associations. In the kanagata prefecture alone are 1,300 cooperative groups, with over 370,000 firms participating at some level. Probably most of the groups do not provide such comprehensive services as the Keihin Plastic Kanagata, but they do typically offer financing assistance, if not purchasing and order services.

[1] Information for this box comes from interviews conducted by OTA staff in Tokyo, March 1989.

[2] In addition t. paying the fee, companies must have the recommendation Of another member.

Chapter 7

Where We Stand: Public Policy and Technology

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Boxes

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Chapter 7

Where We Stand: Public Policy and Technology

The science and technology policy of the U.S. Government has traditionally been concerned with basic science, health, energy, agriculture, and defense. It has been described as big science deployed to meet big problems,[1] and as mission-oriented rather than diffusion-oriented.[2] With few exceptions (the most important being agriculture and civilian aircraft), U.S. Government policy has not been directed toward helping private enterprises make commercial use of advances in technology. Only recently, as it became painfully obvious that one U.S. industry after another was losing technological leadership, have U.S. policy makers given serious thought to a different approach. Some changes are occurring, and of these, some are real departures from the past. But they have been made in a piecemeal, ad hoc fashion. No comprehensive set of government policies has yet been adopted to promote the use of technology for better performance in manufacturing.

The Federal Government undertook a truly novel venture when it went halves with the semiconductor industry in the Sematech R&D consortium, which seeks to improve the manufacturing process for the industry. Other government-supported R&D consortia have been considered (e.g., to promote R&D for advanced television systems). Repeatedly, Congress has enacted laws that urge the 700-odd Federal laboratories to make their research results more accessible to industry, and to undertake new R&D projects designed and operated in collaboration with industry. In establishing Engineering Research Centers in 18 universities, the National Science Foundation hopes to forge stronger links between academic engineering research and training and the world of industry. NSF is also encouraging U.S. scientists and engineers to acquaint themselves with research results coming out of Japan, and to foster the flow of technology from Japan to this country. A growing number of States are establishing industrial extension services to bring best practice technology to smaller manufacturers, and the U.S. Government is taking some initiatives in the same arena.

These programs represent deliberate actions by Federal, State, and local governments in the United States to improve the use of technology by U.S. manufacturers. Other government actions, also intended to improve industrial performance, work more indirectly. Among these are tax policies, such as the present tax credit for increased R&D or the past program of rapid depreciation for capital investments in up-to-date plant and equipment.[3] Laws protecting intellectual property (e.g., patent and copyright laws) are intended to reward innovation and thus to foster technological advance. Finally, Federal policies adopted for national goals other than international competitiveness may still affect it indirectly. One of these is antitrust law and enforcement.

The following sections describe and analyze government programs and policies as they existed in 1990 from the standpoint of their effect on U.S. manufacturing technology. Chapter 2 of this report, analyzing policy issues and options, discusses programs and approaches that Congress might wish to consider for the future.

INDUSTRIAL EXTENSION

In the United States, government technical and financial assistance to small and medium-sized business is patchy and thin. Federal programs do not begin to compare in size to the $31 billion per year that the Japanese national government pours into its combined program of direct loans and technical assistance to smaller businesses—not to mention the added contributions from prefectures, cities, and city wards, plus the $56 billion in guaranteed loans for small firms underwritten by government institutions.[4]

The U.S. assistance programs are not only much smaller than the Japanese but also more hit-or-miss. Every city in Japan and most rural towns have their industrial halls, or federations of small business, or chambers of commerce, dispensing technical help along with plentiful funding for purchase or lease of

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[1] Alvin M. Weinberg, *Reflections on Big Science* (Oxford: Pergamon Press, 1967).

[2] Henry Ergas, 'Does Technology Policy Matter?' *Technology and Global Industry: Companies and Nations in the World Economy* Bruce R. Guile and Harvey Brooks (cd.) (Washington, DC: National Academy Press, 1987).

[3] Discussion of tax policies affecting R&D and capital investment is inch. 2.

[4] For a description of Japanese national government programs to assist smaller businesses, see ch. 6.

the latest production equipment. Japan is blanketed with government or quasi-public institutions at the service of small and medium-size enterprises. In the United States, a small manufacturer in need of technical advice is lucky to find a State or local agency capable of providing it, much less a Federal program that fits his needs.

Small firms form a sizable minority in U.S. manufacturing. Some 358,000 small and medium-size firms (defined as those with fewer than 500 employees) account for 98.8 percent of all manufacturing enterprises, and 35 percent of the manufacturing work forces According to one estimate, these small firms represented 21 percent of value added in manufacturing in 1982.[6] However, employment may be a better gauge of the contribution of small firms to manufacturing, since wages are the major component of value added and wages are lower in small manufacturing firms than in larger ones.

Many small outfits are suppliers of essential materials and parts for large manufacturing firms, and they are especially important in metalworking—the fabrication and machining of metal parts. Over 94 percent of the firms in five major metalworking industries are small plants with fewer than 100 employees.[7] How well these firms do their jobs affects the cost, quality, and marketability of major products from kitchen appliances to automobiles to bulldozers, drilling rigs, and jet airliners. Small to medium-size metalworking firms are also the heart of the industries making production machinery, from tools, dies, and jigs to block-long papermaking machines. In other words, the technological upgrading of small and medium-sized manufacturers has nationwide economic implications.

Many of these firms need technological upgrading. This does not mean that small factories need to install 21st-century computer-integrated manufacturing systems. It does mean they need to acquire up-to-date equipment, train people to use it well, and organize work efficiently. Getting best practice technology out to all corners of U.S. manufacturing is not easy. Owners of small manufacturing firms are often too busy doing a dozen jobs to find out for themselves about technology improvements. Many do not have their own manufacturing engineers, because the engineers cost too much, or are not needed full time, or are unavailable in out-of-the way places where some manufacturing plants are located. Consulting engineering firms are usually more geared to serving large clients than small ones, and many small manufacturers don't trust their ability to find a consultant who will tailor his advice to what the manufacturer needs rather than what the consultant has to sell. Vendors of production equipment can be good sources of technical advice, but often they fall short of what is needed, especially in adapting software to fit particular firms' requirements and in training workers to use the equipment. According to one director of a State industrial extension service, you can't just throw in a computer and read the manual-you have to train people. "We've had lots of companies with computers in their closets. " Finally, financing is the biggest hurdle for many small manufacturers. A small firm is less likely than a big one to have the contacts or track record needed to get loans or otherwise raise money for modernization, and financing is often more expensive for small firms.

Federal Programs for Technology Diffusion to Small Manufacturers

Recognizing the gaps in technology diffusion to small and medium-size manufacturers, Congress has recently created new programs of technical assistance to smaller firms. The Federal effort is still quite limited, however, and there are no Federal loan programs specifically aimed at promoting the adoption of new technologies by small manufacturers. In fiscal year 1989, financial aid administered by the Small Business Administration amounted to $47.3 million in direct loans (which are available only to disadvantaged people) $3.6 billion in loan guarantees, and a contribution of about $150 million to two quasi-public financing agencies for small firms. This

[5] *The State of Small Business: A Report of the President* (Washington, DC: U.S. Government Printing Office, 1989), table A.15, pp. 80-81, and table A. 17, pp. 84-5. The Japanese sector is more heavily weighted toward smaller fins; establishments with fewer than 300 employees are 99.5 percent of all manufacturing establishments and employ 74 percent of the sectoral work force.

[6] Joel Popkin & Co., "Small Business Gross Product Originating: 1958 -1982," contract report to the Office of Advocacy, Small Business Administration, cited in ibid., p. 31.

[7] In 1986, there were 134,700 enterprises in the five major 2-digit metalworking sectors, Fabricated Metal Products, Machinery except Electrical, Electric and Electronic Equipment, Transportation Equipment, and Instruments and Related Products (SIC 34-38), and of these, 126,700 were small enterprises with fewer than 1(X) employees. Ibid., table A.18, pp. 86-87.

aid is given to all kinds of small and medium-size firms (most small businesses are in retail trade and other services) for all kinds of purposes which may have little to do with improving technology.

The biggest U.S. Government program promoting technology advances in small manufacturing is the Small Business Innovation Research (SBIR) program, established by Congress in 1982.[8] Under this program, Federal agencies with R&D budgets of more than $100 million per year must set aside 1.25 percent to help small and medium-size firms compete for Federal research contracts and support these small firms in bringing their R&D results to the point of commercialization. In 1987, 1,276 small companies were awarded $350 million to do R&D work for 11 Federal agencies. The first phase in the SBIR program is feasibility studies of promising ideas (2,189 awards in 1987, for a total of $109 million); the next is development of the ideas with the greatest potential (768 awards, $241 million). SBIR does not fund the final stages of bringing a product to market, but the Small Business Administration does help firms that have gained a place in the R&D program find private financing for commercialization.

SBIR has been given high marks for funneling Federal R&D money to small fins, and for helping young, innovative companies develop advanced technology products.[9] Most of the projects are in the areas of defense, health, and energy, where Federal R&D is concentrated but where commercial possibilities are often limited. The program has been especially helpful, however, in at least one commercially oriented field-biotechnology .10 What SBIR does not do, and was not designed to do, is give best practice technical assistance to the great majority of small manufacturing businesses, which are not involved in the development of products or processes at the frontier of advancing technology.

The Small Business Administration runs a few programs that dispense business management and marketing advice to the ordinary small company (which, as noted, is most often in services or retail trade). One of these is the counseling and brief workshops on business management offered by volunteers, the Service Corps of Retired Executives (budgeted at $2.5 million). Another is the Small Business Development Centers, mostly located on university campuses, which provide counsel from faculty or students on particular problems, some of which may be technical. There are 53 such centers nationwide, in all but four States; about half their funding comes from the government ($45 million in fiscal year 1989) and the rest from the universities. Useful as these programs are, they are not focused on the choice and use of technology in manufacturing.

Federal programs that concentrate on improving manufacturing fins' use of technology come down to a very few. The oldest and largest is the Manufacturing Technology (ManTech) program of the Department of Defense, funded at $175.5 million in fiscal year 1990. ManTech was created to encourage the development and use of innovative manufacturing technologies, and thus strengthen the U.S. defense industrial base. The program is directed to large companies as much as small ones, and is concerned with production of military goods. Most of the ManTech money goes to large defense contractors, often for rather narrow projects promising near-term savings. 11 However, some ManTech projects have brought forth new manufacturing technologies of broad importance, civilian as well as military. Numerically controlled machine tools were developed in a ManTech project. More recent projects with possible commercial applications include work on near net shaping of metals and computer integrated manufacturing systems.

If the funding for ManTech programs (varying up and down from $130 million to $200 million in the 1980s) seems a minuscule portion of the Defense Department's $40 billion R&D budget, it looms very

[8] The Small Business Innovation Development Act of 1982 established SBIR.

[9] Comptroller General of the United States, General Accounting Office, *Implementing the Small Business Innovation Development Act—The First 2 Years,* GAO/RCED-86-13 (Washington, DC: October 1985); *A Profile of Selected Firms Awarded Small Business Innovation Research Funds*, GAO-RCED-86-113FS (Washington, DC: 1986); *Effectiveness of Small Business innovation Research Program Procedures* GAO/RCED-87-63 (Washington, DC: 1987); Small *Business Innovation Research Participants Give Program High Marks,* GAO-RCED-87-161BR (Washington, DC: 1987).

[10] U.S. Congress, Office of Technology Assessment, New *Development in Biotechnology: U.S. Investment in Biotechnology,* OTA-BA-360 (Springfield, VA: National Technical Information Service, 1988). OTA found that "SBIR funds are one of the few sources of direct Federal support for applied research and development.

[11] Manufacturing Studies Board, Manufacturing *Technology: Cornerstone of a Renewed Defense Industrial Base* (Washington, DC: National Academy Press, 1987).

large compared to Federal spending for manufacturing technology on the commercial side-especially diffusion of technology to small manufacture. Technology diffusion programs include the 28-year-old Trade Adjustment Assistance, and the newly minted Manufacturing Technology Centers (MTCs), created in the 1988 trade act and operated by the National Institute of Standards and Technology (NIST, formerly the National Bureau of Standards).[12]

Trade Adjustment Assistance (TAA) for firms is open only to companies that can show they were hurt by imports.[13] It has usually been funded at about $15 to $16 million per year but in recent years its prospects were uncertain (the Reagan Administration repeatedly proposed to abolish it) and its funding was cut. In fiscal year 1990 it received $9.9 million in new and carryover funds. Nevertheless, until 1988 TAA was the major Federal program giving one-on-one technical assistance to small and medium-size manufacturers. The TAA program also gives advice to its clients on such things as marketing and advertising, inventory control, and financial management. Help is provided by 12 small, regional, non-profit centers that act, in effect, as industrial extension agencies.

The new Manufacturing Technology Centers are charged generally with transfer of advanced technology to industry, with special emphasis on U.S.-based small and medium-sized manufacturers. The law directs the centers to make new manufacturing technology ''usable" to these smaller firms; actively provide them with technical and management information about manufacturing; establish demonstration centers for advanced production technologies; and, for small firms with fewer than 100 employees, make short-term loans of advanced manufacturing equipment. So far, three federally funded Manufacturing Technology Centers (in Troy NY, Cleveland OH, and Columbia SC) have been established in the United States and three more are planned. The three existing centers got a total of $4.5 million in Federal funds in 1989; matching funds from local sources are required.

NIST expects the Manufacturing Technology Centers to serve primarily small firms with 200 or fewer employees, and to concentrate more on off-the-shelf best practice technologies than on high-tech cutting edge systems fresh from the R&D lab. NIST officials also say that the primary service offered by the Centers will be modernization plans, customized to fit the needs of individual firms. However, the language of the law gives NIST latitude to support Centers with varying approaches, and so far it has done so. The Troy MTC is concentrating on transfer of high-technology systems from labs to selected fins, though it also cooperates with State agencies and community colleges in diffusing best practice to a broad range of client firms. Field agents of the Cleveland MTC are knocking on doors of thousands of small companies in a concentrated industrial area and offering those that respond individual business and technical plans. The South Carolina MTC, which is closely linked to the State's technical college system, is installing centers to demonstrate computerized metalworking equipment.

NIST has its own small demonstration center in the Shop of the 90s. This is a working machine shop that fills job orders from government agencies but also serves a technology extension purpose. It is an offshoot of NIST's highly automated, state-of-the-art Advanced Manufacturing Research Facility (AMRF), which was meant to serve in part as a learning center for manufacturers. However, many people from small manufacturing firms found the AMRF entirely too advanced to have any practical application to their businesses. The Shop of the 90s, using off-the-shelf technology, fits their needs and experience better. Because it is a working shop, with 60 employees and a business worth about $4 million a year, the manager has credibility with small manufacturers. State technology agents are brought in for presentations, and the Shop is open for tours and phone inquiries.

One more small NIST program, also created in the 1988 trade act, is intended to provide technical and financial assistance to State technology extension

[12] Neither program is strictly limited to small and medium-size manufacturers, but in practice TM has mostly served small manufacturing firms, and the law creating the Manufacturing Technology Centers emphasizes dissemination of new technology to small and medium-size manufacturers. See the Omnibus Trade and Competitiveness Act of 1988 (Public Law 1O(H18), Subpart B, Sec. 5121(a).

[13] Trade Adjustment Assistance also includes a reemployment and retraining program for workers losing their jobs due to imports; this part Of TAA is far bigger (recently funded at about $200 million per year) and better-known than TM for firms. For a description and evaluation of both programs, see U.S. Congress, Office of Technology Assessment, *Trade Adjustment Assistance: New Ideas for an Old Program—Special Report,* OTA-ITE-346 (Springfield, VA: National Technical Information Service, 1987).

services. This program got no funding until fiscal year 1990, when it received $1.3 million, but NIST had already begun some modest outreach to States. So far, it has mostly been a one-man show—a single NIST official (sometimes accompanied by the manager of the Shop of the 90s) who travels to State technology agencies explaining what resources NIST has to offer, referring them to other sources of Federal help, and helping various State agencies make contact with each other.

Another federally funded technology demonstration center has been in business since 1988. That is the National Apparel Technology Center in Raleigh, NC, an outgrowth of the 10-year-old TC^2 project. TC^2 (Textile/Clothing Technology Corporation) began as a combined government-industry effort to develop a flexible, automated sewing system able to take on a variety of complicated sewing jobs, such as attaching the sleeve in a man's suit jacket. Although it has fallen short of some of its ambitious technical goals, has produced some commercially usable automated sewing equipment. In addition, TC^2 now supports the Raleigh center, which demonstrates a whole range of modern apparel-making equipment to its member companies, large and small, and arranges seminars with apparel engineering faculty of nearby North Carolina State University. The Federal Government's contribution to TC^2 has been $3.5 million per year for the past few years. The Defense Logistics Agency also operates three demonstration centers for apparel technology, each funded at up to $5 million per year, with three-quarters Federal funding. These centers are open to civilian manufacturers as well as defense contractors.

Altogether, these Federal technology extension efforts are scattered and small. Up to now, the emphasis in Federal technology transfer programs for small manufacturers has been much more on pushing out sophisticated new products and processes (as in the SBIR program) than on helping individual firms adopt best practice technology.

State Industrial Extension Programs

Most of the action in industrial extension is in the States, and even there it is limited, though increasing. Exactly how much it amounts to is uncertain, partly because surveys of State programs are incomplete and quickly outdated, and partly because "industrial extension" is not very well defined in the surveys. More than 40 States have programs to ''promote technology," but most of their effort and funding goes for research and development in universities and for aid to high-technology startup ventures-not for help to existing firms in adopting best practice technology. According to a survey of State programs done for NIST in 1988-89, only 13 programs in nine States had technology extension programs whose main purpose was direct consultation with manufacturers on the use of technology .14 However, this number is already out of date. At least one new program, Nebraska's, was established after the survey was completed.

One of the better recent surveys of State technology programs was done by the Minnesota Governor's Office of Science and Technology .15 It found that in 1988 States directly spent $550 million on various kinds of technology programs, but only about 10 percent of that—some $57 million—went for technology transfer and technology/managerial assistance (table 7-l). Technology transfer, which got $46 million (8 percent) of the finds, was defined as facilitating "the transmission of new technologies from the laboratory to the private sector. . . for the creation of new businesses, the introduction of new product lines for established firms, or the revitalization of mature industries."[16] Despite this language, some activities that States call "technology transfer" might really be closer to industrial extension services. At a guess, the States are spending some $25 million to $40 million for such services.

As used here, industrial extension means a service something like this: an accessible office staffed with a few engineers or people with experience in industry invites telephone calls or visits from managers of small manufacturing firms seeking

[14] Donald R. Johnson, Acting Director, Technology Services, National Institute of Standards and Technology, testimony before the U.S. House of Representatives, Committee on Small Business, Sept. 28, 1989.

[15] Governor's Office of Science and Technology, *State Technology Programs in the United States, 1988* (St. Paul, MN: Minnesota Department Of Energy and Economic Development, 1988).

[16] Ibid., p. 1.

Table 7-l—Expenditure on State Technology Programs, FY 1986 and FY 1988

	Expenditures				Number of States with programs FY 1988	Average State spending FY 1988
	FY 1986[a]		FY 1988a			
Type of program	$ Million	Percent	$ Million	Percent		$ Million
Technology/research centers	285.6	41.0	226.6	41.2	29	7.8
Research grants	126.7	18.2	150.2	27.3	25	6.0
Venture/seed capital	159.6	22.9	37.4	6.8	18	2.1
Research Parks/incubators	75.6	10.9	36.9	6.7	22	1.7
Technology/managerial assistance	10.5	1.5	11.0	2.0	30	0.4
Technology transfer	8.4	1.2	45.7	8.3	26	1.8
Other technology programs	30.1	4.3	42.4	7.7	41	1.0
	700.0[b]	100.0[b]	550.0	100.0	44[c]	12.5

Notes:
a There are differences in accounting procedures between the 1986 and 1988 reports, For some states, the 1986 figures represented muiti-year appropriations. The 1988 figures are all on an annual basis.
b column sum does not add to total because of rounding.
c Number of States with one or more technology Programs.

SOURCE: Calculated from: Governor's Office of Science and Technology, *State Technology Programs in the United States,* (St. Paul, MN: Minnesota Department of Energy and Economic Development, September 1986); Governor's Office of Science and Technology, State *Technology Programs in the United States, 1988*, (St. Paul, MN: Minnesota Department of Trade and Economic Development, July 1988).

help. Promptly after the first interview, the office sends a technical specialist (either someone from its own staff or an engineer from the State university) to make an onsite diagnosis. Then the extension service produces a customized client report, and its technical specialist or a consultant works one-on-one with the firm to put into effect the improvements recommended by the service and accepted by the firm's manager.

What small manufacturers need more than the newest technologies fresh out of the laboratory is off-the-shelf hardware and software and individual help in choosing and managing them. They need advice on these choices from an independent source with no financial stake in the selection. And they need to understand how much training is involved in adopting new equipment, and where to get it. These conclusions are drawn from the experience of people involved in technology extension, both the agents providing the services and the firms receiving them. In visits and interviews with five State industrial extension programs in 1988, OTA found that the programs were serving genuine needs that were not otherwise being met, and that demand for the services was high.[17] At least two of the States—Georgia and Maryland-do not advertise the services they offer for fear of being swamped with requests for assistance. (Box 7-A lists and briefly describes the programs OTA visited.)

Individual Problem Solving

Everyone interviewed took it as given that one-on-one contact between technical specialists and company managers is the bedrock of industrial extension. A good hard look at the company's individual problems is the starting point for all the programs. This often includes an intensive telephone interview to begin with, followed by a site visit and a diagnostic report. Again and again, company managers remarked on the value of an objective, experienced outsider taking a fresh look at the company's problems—something that managers of small outfits are often too swamped to do. ''I don't have time to do research,'' said Jerry Lipkin, Executive Vice-President of Moyco Industries, a Philadelphia manufacturer of abrasives and dental products. "I have to do sales, marketing, and personnel. '

Sometimes, the diagnosis may find that a company's efforts to modernize are misdirected, or that real problems have escaped the manager's attention. According to Travis Walton, director of Maryland's Technology Extension System (TES), some companies think they need sophisticated computer equipment when they don't. For example, "If you make the same product year after year you don't need CAD (computer-aided design)—you only need it if you customize. ' One company, Travis added, came to TES for aid in setting up a computer system to

[17] Findings from these visits and interviews are also reported in Philip Shapira, ''Industrial Extension: Learning from Experience,' contractor report to the Office of Technology Assessment, November 1988.

Box 7-A—Five State Industrial Extension Programs

In 1988 OTA visited five industrial extension programs in four States, some with long experience and some just a few years old. Through interviews with program managers, extension agents, and clients, OTA sought information on the kinds of technical assistance small manufacturers need and how the programs are meeting the needs. The five programs, with acronyms and year of origin, are:

Georgia Institute of Technology Industrial Extension Regional Offices (GTRI, 1960) is headquartered at Georgia Tech in Atlanta and supports 12 regional offices, each with a field staff of two or three people giving individual service to client fins, The regional offices also link clients with specialized services at Georgia Tech, including assistance on productivity, energy conservation, workplace safety, hazardous waste management, and training. Funded at $3.8 million in 1988, GTRI had 26 professional employees and served 960 firms. Days of field service averaged 2 to 5 and the average cost per client was $4,000.

Maryland Technology Extension Service (TES, 1983), based at the University of Maryland, offers one-on-one client assistance at five regional offices. Field staff may refer problems to the university faculty. With a full-time staff of seven people, and funding of about $400,000, TES served 250 to 300 clients in 1988, giving up to 5 days of service at an average cost per client of about $1,500.

Michigan Modernization Service (MMS, 1985) is a State-sponsored program, affiliated with Michigan's Industrial Technology Institute. Its services include intensive diagnosis and onsite visits from a field representative, experienced in industry and manufacturing technology, paired with a training specialist. Some 45 people staff the program, but most of the 25 professionals are part-time consultants. The 1988 budget was $2.8 million (expected to rise to $3.9 million in 1989) and 140 clients were served (250 expected in 1989). Cost per client was about $20,000 for an average of 6 days of service.

Pennsylvania Technical Assistance Program (PENNTAP, 1965), a joint program of Penn State University and the Pennsylvania Department of Commerce, provides technical information from faculty specialists and some onsite visits, in response to client requests. Sometimes PENNTAP takes the initiative in acquainting firms with new technologies. Total budget in 1988 (including in-kind facilities and services donated by the University) was about $1.3 million and the staff was equal to 12 1/2 full-time slots. Some 850 firms and 450 local government bodies received services; cost per industry client was $1,100 to $1,500. The length of service was not reported.

Pennsylvania Technology Management Group (TMG, 1984), a nonprofit corporation sponsored by the State, concentrates on bringing best practice technology to small manufacturers (defined as having fewer than 250 employees, but in practice usually in the range of 20 to 40 employees). One of the small core staff (6 people) evaluates the client's problems, and TMG then shares the cost of a consultant, if needed. With a budget of $350,000 in 1988, TMG served about 40 clients, at an average cost of $8,800. The length of service averaged 8 days.

track inventory, but the real problem was that the inventory was "totally chaotic" and far too big, tying up capital in unneeded items.

Another example comes from the Tnemec Co., Inc. of Baltimore. This branch plant of a small company ($1 3 million sales per year) makes industrial protective coatings for water towers, wastewater plants, and the like. Tnemec wanted to expand to handle a growing business, but the plant manager, Frank Lavin, recognized that he needed help in planning the expansion. "I'm in a small business with a busy day-to-day routine, ' he said. ''I don't know how to build a new plant, ' He called on TES. In a site visit, the TES engineer found that a complicated, inefficient flow of materials had developed over the years in the old plant, and suggested a wholesale rearrangement. The result was that the company got the space it needed in only 25,000 square feet, not 40,000 square feet as originally planned. ''At $25 a square foot, we saved a lot of money," Lavin said. He added that if he had asked a consulting firm for 40,000 square feet, they would have built it without question. "Consulting engineers and architects build what you ask them to.

Trust

Lavin, like other company managers, praised the ''objectivity and the expertise of the State extension service. Trust in the services' impartiality-the fact they are not trying to sell the companies anything or collect big fees—is a key element in their success. This was the reason several plant owners and managers gave for turning to a State agency instead of a private consultant. Besides, they said, small firms have trouble getting competent

service from consulting engineers. One said bluntly: "They are a waste of time and expensive."

Brooks Manufacturing is one company that struck out in trying to find the right private consultant. This Philadelphia firm has a $6-million-a-year business making electrical outlet strips, but it faces growing competition (especially from Taiwan) in its basic product line. Brooks is trying to build up its business in more specialized, higher value-added items— electrical outlet strips for medical carts, for example and is developing a special power strip that is compatible with sophisticated communications equipment. But the company is too small to support a research and development department to design its new products, and it failed to get what it needed from three different consulting engineers. "The engineering service consultants usually send out the new guys to small fins, " President Gary Brooks said.

Pennsylvania's Technology Management Group (TMG) stepped in and helped Brooks find a capable engineering consultant, who developed new product designs and made blueprints for the company. TMG also funded an evaluation of the company's operations to see whether it needed and could handle a Materials Requirements Planning (MRP) system, which takes an order and breaks it down into the individual components and material needed to fill that order. On the basis of the evaluation, Brooks adopted the system. TMG also found a qualified consultant to help the firm tailor the system to its needs.

At Moyco Industries in Philadelphia, Jerry Lipkin remarked that the intervention of TMG in finding a consultant meant that the fees were predictable and there was a cap on final costs. "We have been burned by consultants in the past, and the program's involvement helps reduce the risk of this happening." That TMG puts up a little money (maximum of $1 ,500) toward the consultant's fee reassures the company that TMG too has a stake in the outcome, and that the consultant is qualified. For their part, consultants seem to welcome referrals from State extension services since this adds to their credibility and opens doors to new business.

Extension services operating out of university engineering departments can use members of their own departments for consultations. For example, when American Bottlers Equipment Co. (Ambec) of Owings Mills, MD, came to Maryland's Technology Extension Service for help in computerizing its parts list and linking the list with computerized drawings, the service used its university connection. TES works out of five regional offices but is based in the Engineering Research Center of the University of Maryland; it calls on engineering faculty members in nearly half its cases. Travis Walton, director of the program, says TES has a "visiting nurse" approach— the engineers who staff the regional offices do what they know how to do and call for help when the problem is beyond them.

Ambec is a small company specializing in the manufacture of stainless steel conveying and handling equipment for customers in the food and beverage, pharmaceutical, electronics and other industries. It has sales of $10 million per year and about 100 employees. Essentially a job shop, Ambec works to customer specifications, using families of parts which it assembles to meet a particular customer's needs. Before consulting TES, Ambec had gone through a bad experience with a private consulting firm, which sold it a Material Resource Planning software system that was supposed to keep track of orders and parts, but never worked as promised. Instead of trying that route again, the company called on the State extension service. TES linked Ambec with a University of Maryland engineering professor and a student with good computer skills. The student developed the program Ambec wanted and later went to work full time for the company.

Confidence in an extension service's competence is as important to a company as trust in its objectivity. Connections with an institution that is already well respected throughout the State help to establish that confidence. In Maryland, for example, that institution is the University's highly regarded engineering department. In Pennsylvania it is Penn State University, in Georgia it is Georgia Tech, in Michigan it is the Industrial Technology Institute in Ann Arbor.

Sometimes, only experience will instill confidence. Terry Brady, president of Bradhart, Inc. of Howell MI, consulted the Michigan Modernization Service--MMS) only as a last resort. Bradhart is a small but top-of-the-line job shop, machining high-quality metal parts, especially bearings, to the specifications of its customers in the aerospace, ordnance, and oil industries. To stay competitive in the new global economy, the company decided to modernize. Moving to larger quarters, it installed

several computer numerically controlled (CNC) machine tools and a computer system to integrate orders and office processing with production. This investment cost half a million dollars-a lot for a company with sales of $3 million per year. Unfortunately, the company's managers soon discovered that they had seriously underestimated the startup costs for training workers to use the new tools. Further, the software for the computer system did not run properly. The company had run out of credit. It was in a make-or-break position.

At this point, Brady called MMS, but without much hope of real help. He was surprised, frost at getting a prompt businesslike response, and still more so at the quality of training and other assistance MMS was able to provide. Finally, MMS gave Brady a vital boost in confidence when its evaluation confirmed that the company was right to invest heavily in modern equipment, and was headed in the right direction. Brady remarked appreciatively on the way MMS staff had served as a "sounding board," providing advisors who were not competitors but still had an understanding of business and technology. "I still don't believe," he said, "that someone would want to help the little guy. "

Training

Nothing could better illustrate the importance of training on new equipment than the Bradhart story. Because the managers did not appreciate how much training would cost, the company almost went under in an otherwise sensible move to modernize. Fortunately, MMS was able to help Bradhart get State training funds and find good training programs. (As discussed below, MMS also helped the company get a bank loan to tide it over the crunch, before the investment in equipment and training began to pay off.)

With help from MMS, Bradhart set up training programs for employees, both in-house and at a local community college. Shopfloor employees received training on the CNC tools and in quality control techniques; the office staff was trained in spreadsheet and database programs and job costing. In addition, the company sent four or five employees at a time through a local community college to learn basic mathematics, quality control, and supervisory skills. MMS also helped Bradhart untangle its software.

Although the directors and staff in all five industrial extension services stressed the importance of training, MMS was the only one with a training element routinely built into its services. It took time for MMS to recognize the merits of marrying training with technology. In its early days (perhaps influenced by General Motors, which was then trying to automate everything it could in auto assembly) the program concentrated on hardware, and training to use the hardware was not much emphasized. Today, MMS takes care to emphasize that it is not hawking technology per se but is helping firms use technology, which means developing management and training. On every site visit, MMS sends pairs of training and technology specialists to make the diagnosis and write the report, which includes an assessment of training needs and options for every client and actively helps clients design or procure training. The Michigan program spends roughly $1 dollar on training assistance for every $2 dollars it spends on technology deployment.

Other industrial extension services, though less systematic about training than MMS, also know where to refer clients for training advice and assistance. For example, Pennsylvania's TMG linked Brooks Manufacturing with a community college to get training in quality control, statistics, teamwork, and basic math for its workers. However, some of the services have a harder time finding adequate training. Georgia Tech has a small industrial training unit able to provide limited training, mostly for frost line supervisors. But in some of its cases, training that extension agents recommend, and companies are eager to get, is not available.

For example, in a productivity audit of Imperial Cup's paper and plastic cup manufacturing plant in La Fayette, GA, the Georgia Tech engineer included several recommendations for improved training. She found the current training-2 days under a fret-line supervisor-inadequate for working with the sophisticated machinery in the company's paper department. Imperial tried to get a local vocational-technical school to train workers on the shop floor, but the school offered only classroom training. The company also had trouble finding workers with the skills needed to maintain the machinery. The local voc-ed school turned out electronics and auto technicians, but not machinery repairers. In the past, the company sent small groups of workers to the machinery manufacturer in Wisconsin for training, but the manufacturer recently expressed reluctance

to continue it. At the time of OTA's visit, no solution to Imperial's training needs was in sight.

Financial Aid

Industrial extension services do not provide funds for capital investment or operating expenses. They are in the business of giving technical, not financial, assistance. However, they can help small firms coming to them with financial problems in two ways. First, their diagnosis may reveal that what the firm's manager thought was a need for funds is really more a problem of management that can be solved, say, with a better use of space, flow of materials, or control of inventory.

Second, the State agency can be very useful in directing firms to sources of funds, and supporting them in dealings with banks. For example, the Michigan Modernization Service not only pointed the Bradhart company toward State funds that could help pay the big bills for their training needs. MMS also helped the company get a bank loan, using State economic development funds as equity (the funds came from Community Development Block Grants, contributed by the Federal Government to the States). "This lessened the financial pressures," said Terry Brady, Bradhart's president. "We would have gone down without the State's help."

Besides the block grants and other economic development funds, many States have special loan programs for small businesses that extension services can tap. The extension services can also plug into the Federal program of small business guaranteed loans. It is safe to say, however, that finding the money to modernize a factory is a serious hurdle for many small manufacturing firms in the United States. They do not have the many options of the small Japanese firm, which can afford to pass up a low-interest government loan in favor of a bank loan at a slightly higher rate, because the bank takes just one day to consummate the deal, while the government loan might take a whole month (see box 6-A, ch. 6).

Staff, Fees, Intensiveness, and Cost of Services

All the State agencies interviewed by OTA reported that they had found ways of getting good staff-even though most pay their engineers and other technically trained people below-market salaries. For their small core staffs, they look for people with broad technical competence (rather than depth of knowledge in a narrow field) and an interest in working with people as well as things. The Technology Management Group in Pennsylvania calls the kind of person they look for NYTE--not your typical engineer. TMG reports no trouble attracting and keeping staff, even though the pay (on average, $35,000 per year in 1988) is well below the median for engineers. The pay in the Georgia Tech extension service is higher (averaging in the mid-$40,000s), but the program's directors say the satisfaction of the job is at least as important as pay in attracting good people. Most of the extension offices are in rural areas where the agents get plenty of local recognition, both for the job they do and as representatives of prestigious Georgia Tech.

The Michigan Modernization Service relies mostly on part-time consultants for its field representatives, and has been through some periods of high turnover. The program directors say that although it is a challenge to get good people, it can be done. The pay is pegged at the State rate for consultants—$250 per day, which compares with $800 to $1,000 per day for private engineering consultants. The field reps take the work despite the uncompetitive rate, partly because it opens the door for more contracts later, partly because the State does much of the preliminary work—and also partly because they enjoy it. Some of the field reps are retired industry engineers (often from the auto industry) and they are enthusiastic about helping small firms learn how to solve problems for themselves. The MMS has changed its ideas about what makes a good field representative. At first, they looked for people with specific technical qualifications. Now they look for breadth and the ability to establish trust, listen, and write a good analytic report.

With its large roster of part-time field representatives (25 in 1988), MMS does not often need outside consultants, but other programs (TMG in particular) use private consultants quite regularly. TES relies heavily on its faculty connections (using them for 45 percent of clients), and the Georgia Tech extension offices taps the resources of the Georgia Tech Research Institute in Atlanta for about 30 percent of its clients. Thus, these programs are able to tackle a shifting variety of technical problems while keeping only a small permanent staff for continuity and a sense of mission.

None of the State programs charges a fee for its initial assessment. Only one, TMG, charges any fee at all; in this program, firms pay apart (usually about

two-thirds) of the fee for consultants. The fact that the firms pay nothing for the diagnostic assessment makes it easy for them to enter the program, even when (like the Bradhart company) they don't have very high hopes for it. Many of the company managers interviewed by OTA said they would be glad-next time-to pay for services they got from the extension agencies. The problem with paying up front is that they have no idea whether the agency will deliver professional level services. In the case of TMG, firms get their diagnosis before they are asked to share payment for a consultant. And about 60 percent decide not to go ahead (though many of these are able to make improvements on their own, based on the diagnosis). Those that choose to go forward know what their cost will be, since TMG takes responsibility for dealing with the consultant. The Michigan program is considering a second phase of service that might charge user fees, but this would follow the first, no-charge phase.

The cost per client of the five programs ran from about $1,000 to $20,000 in 1988 (box 7-A). There seemed to be a rough correspondence between the cost and the intensiveness of the services clients receive, although it is hard to say this definitively because definitions of services differ, and so do allocations of cost. MMS and TMG, both of which emphasize field visits and individual consultations based on a written diagnostic assessment, are at the high end. MMS reported an average of 6 days of service and a cost of $20,000 per client. TMG said it gave an average of 8 days of service, at a cost of $8,800 per client—but the cost rose to $19,400 for those clients (40 percent) who elected to use a consultant.

Maryland's TES and the Georgia Tech extension service both give up to 5 days service to their clients, though neither is rigid about "setting" the clock running.' TES ' 'usually' makes field visits, though not always. Georgia Tech may or may not; one regional office reported having contact with 200 companies in a year, helping 100 in depth, and making about 50 site visits. Another said that some field officers are so familiar with a firm after dealing with it over the years (Georgia Tech has been in the industrial extension business since 1960) that a site visit isn't necessary. Both tend to give their clients oral, not written reports. And both rely for specialized technical help on their university connections, not private consultants. TES pays its faculty advisors for their time only when asked, and then at their university salary (not private consultant) rates. The faculty advisors may then use the money for professional purposes such as travel or research support. Georgia Tech can call on its parent organization for extra services to its clients-for example, a productivity audit from the State-funded Georgia Productivity Center program. The TES cost per client is nominally $1,500, but most of the cost of consultation with engineering faculty at the University of Maryland is not included in this figure. Georgia Tech reported a cost per client of $4,000.

The least expensive of these programs, PENNTAP, generally offers the least intensive services. Often, the problems that companies bring to it are narrowly technical and can be handled by a telephone call, a fax message, or group meetings. PENNTAP's eight staff specialists (mostly engineers) do make site visits as well, however, and they tailor responses to clients' individual problems. According to the program's director, human contact is the key to technology dissemination. PENNTAP reported spending about $1,100 to $1,500 per client firm, with no estimate of the days of service rendered.

Improvements in Services Offered

Most of the people OTA interviewed, including the staffs of the five extension services and their clients, thought the programs were doing a good and much-needed job. If there is one change they all want to make, it is to expand the programs and serve more firms, Two of the extension services, Georgia Tech and Maryland's TES, specifically stated that they don't advertise for fear of attracting too much business. Georgia Tech asked the State legislature for funds to open five more regional offices. Michigan's service was expanding in 1989, and Pennsylvania established a new $10 million-a-year program of Industrial Resource Centers, replacing the much smaller TMG, which will serve as advisor to the new centers.

At one of the programs, MMS, the staff had given serious thought to expanding services to individual companies, as well as extending service to more companies. MMS staff members believe that the average of 6 days of service they now give clients is about right for a first bite. "Small and medium-size firms face a digestion issue," said Alan Baum, director of research and analysis. "They can only deal with so much at a time. " But the staff is seriously considering offering a second phase of

assistance of up to 20 days, with the firm paying for some or all of the costs (the first phase, as noted above, is free).

MMS has another idea in mind as well. That is to strengthen horizontal links between small firms in the same or closely connected businesses, freeing them from too-great dependence on the larger firms that are their customers. Interestingly, managers of Japanese Government programs for small manufacturers are promoting more independence in much the same way, through networks that provide cooperative product development and marketing services (see ch. 6). Michigan's Industrial Technology Institute, of which MMS is now a part, has made some preliminary moves in this direction. Its PRIME project (Program of Research in Modernization Economics), started in 1985, is helping Michigan auto parts and components suppliers meet new demands from the Big Three automakers—especially the demand for complete subassemblies rather than disparate parts. For example, PRIME might link a small foundry with a machine shop so the two together could make a complete camshaft subassembly.

Finally, some of the extension services-notably Georgia Tech-would like to do more with training. They believe that the training programs they currently offer are too "off-the-shelf" and depend too much on the classroom. And they think that closer links between industrial extension and State vocational educational systems are a must.

It would be a mistake to consider the examples discussed above as typical of industrial extension services in the United States. They are not. OTA chose these five programs to examine not because they are typical but because they are among the most active and the best. The purpose was to suggest what *can be* done with technical assistance to small manufacturers, not to suggest that it *is* being done nationwide. The situation is patchy. Several States besides the four mentioned here also have active programs, others are following the leaders and establishing industrial extension services, and some are doing little if anything. An accurate count is not available, but it is likely that the State and Federal programs combined are spending no more than $40 to $50 million per year on industrial extension. If just 24,000 small American manufacturing firms were to receive industrial extension services each year (about 7 percent of small manufacturers roughly similar to the proportion that is served in Georgia by the Georgia Tech extension service), the total cost would be $120 million to $480 million per year, depending on the level of service.[18]

COMMERCIALIZING TECHNOLOGY FROM FEDERAL LABORATORIES

During the 1980s, the government has tried to encourage the commercialization of technology from the Federal labs by private industry, Congress has passed several laws to promote it; scientific advisers to the President and executive agencies have strongly urged it; and President Reagan signed an Executive Order laying out guidelines to accomplish it.[19] The effects have been positive but modest. The Federal labs still have a long way to go before realizing their potential as a source of new ideas for industry.

When the interaction works, lab-generated technologies can have an impact. For example, although it focuses on nuclear weapons research for the U.S. Department of Energy (DOE), Sandia National Laboratories has also made contributions to civilian industry. Sandia helped to develop important clean room technology and the hot-solder leveler, used in electronics manufacturing. Each was worth over

18See ch. 2 for more detail on these estimates.

19The laws promoting technology transfer include the Stevenson-Wydler Technology Innovation Act of 1980, the Patent and Trademark Amendments Act of 1980, the Bayh-Dole Patent Amendments of 1984, the Federal Technology Transfer Act of 1986, the Omnibus Trade and Competitiveness Act of 1988, and the National Competitiveness Technology Transfer Act of 1989. Also, during 1988-89, subcommittees of the House Committee on Science, Space, and Technology and of the Senate Committee on Energy and Natural Resources held hearings on technology transfer. Major reports to the executive branch include *Report of the White House Science Council Federal Laboratory Review Panel, Office* of Science and Technology Policy, Executive Office of the President, 1983; Energy Research Advisory Board, ***Research and Technology Utilization: A Report** of the **Energy Research Advisory Board to the UniteStates Department of Energy,* DOE/S-0067, *1988; and The Federal Technology Transfer Act of 1986: The First 2 Years,*** Report to the President and Congress form the Secretary of Commerce, July 1989. President Reagan's order establishing guidelines for the Federal labs on technology transfer was Executive Order 12591, Apr. 10, 1987.

$100 million to industry by 1987 according to Sandia's estimates.[20]

Technology transfer is increasing, albeit slowly. Quantitative measures are elusive and fail to capture the key ingredient of personal interaction. Nonetheless, some trends are indicative. Active license agreements between DOE's Oak Ridge National Laboratory and industry were up from 2 in 1985 to 33 in June 1989.[21] Industry increased its royalty payments to DOE labs from $297,000 in FY 1987 to $908,000 in the first 9 months of FY 1989,[22] and are likely to rise further.

The labs were set up mostly to pursue missions other than commercially promising R&D-notably, basic research and the development of science and technology related to weapons—so there are limits to the potential for technology transfer. However, there are also barriers that are not integral to the labs themselves. These can be overcome. Changes in the funding, administration, and orientation of the labs are necessary, and should help the labs to increase their potential contribution to increase U.S. competitiveness in manufacturing. The following sections explore how the labs are responding to legislative and executive mandates to improve technology transfer. While progress has been made, more could still be done to make labs' research available to industry.

The Federal Laboratories: An Overview

The Federal Government spends approximately $21 billion on its labs, mostly through: the Department of Defense (DoD), $10.5 billion; DOE, $4 billion; National Aeronautics & Space Administration (NASA), $2.5 billion; and National Institutes of Health (NIH), $1 billion. Various smaller agencies, such as the Agricultural Research Service, account for the remainder.[23] Most of this money is spent on lab work for defense and basic research. Almost all of DoD's money and about $2 billion of DOE's goes to defense-related R&D, largely weapons development. Most of the DOE labs' remaining resources (after defense-related spending) are spent on basic energy research.

Neither of these two predominant missions, defense and basic research, is directly connected to the needs of the private sector. Not only is defense-related R&D designed to produce weapons systems (not usually transferable to civilian manufacturing), there are security-related barriers which tilt the institutional culture of defense-related researchers producers away from technology transfer into the civilian sector. Basic research faces different, but just as significant, problems in forging links to developers and users of its technology. Basic researchers are almost by definition interested in the pursuit of knowledge, not its application. This tends to be true for both the institution and the individual researcher.

Nevertheless, defense R&D and basic research can sometimes be made useful to commercial manufacturing. Labs differ in their potential to help the private sector, and in their success in giving such help; they come in different sizes and with different structures and orientations. It is therefore useful to begin with a brief overview and some central distinctions.

DOE Labs

The DOE labs are key factors in any discussion of the Federal labs. Indeed, the nine multiprogram DOE labs are usually simply called the national labs, even though they account for only about a sixth of total government spending on Federal labs.

The DOE labs are funded primarily through three program areas,[24] which orient the work that they fund in different directions: Defense Programs ($3 billion) supports the DOE's weapons work and nuclear materials production; Energy Research Programs supports basic research in energy, mainly nuclear energy ($2 billion); and the Nuclear Energy, Fossil Energy, and Conservation and Renewable Energy Programs (collectively referred to below as

[20] *Annual Report: Technology Transfer, Sandia National Laboratories, Fiscal Year 1987*, SAND 87-0749, UC-13, April 1988 (Springfield, VA: National Technical Information Service, 1988), p. 7; Robert Stromberg, Technology Transfer and Policy Department, Sandia National Laboratories, personal communication, June 19, 1989.

[21] Donald Jared, Program Administrator, Office of Technology Applications, Martin Marietta Energy Systems, Inc., Oak Ridge National Laboratory, personal communication, June 20, 1989.

[22] Rees L. Dwyer, III, Executive Assistant to the Assistant Secretary, Management and Administration. Department of Energy, personal communication, Oct. 18, 1989.

[23] National Science Foundation, *Federal Funds for Research and Development: Fiscal Years 1987, 1988, and 1989*, vol. 37, Detailed Statistical Tables, NSF 89-304 (Washington, DC: U.S. Government Riming Office, 1989), p. 29 (estimates for fiscal year 1989) (totals of figures shown for intramural research and research in all Federally Funded Research and Development Centers (FFRDCs)). These figures are by agency, not by lab; agencies sometimes spend money for research in other agencies' labs. See ibid., pp. 4, 31.

[24] Some other agencies also fund R&D in DOE labs.

Applied Energy programs) support various projects beyond basic research that are not related to weapons ($1 ***billion).*** Only Applied Energy has commercialization of technology as a specific part of its institutional mission.

These three programs support the work done in three sets of labs: the four big national labs primarily concerned with defense-related work (Lawrence Livermore, Los Alamos, Sandia, and Idaho Engineering); the five medium-sized national labs that focus primarily on basic research in energy (Argonne, Brookhaven, Lawrence Berkeley, Oak Ridge, and Pacific Northwest); and 28 generally smaller labs (e.g., the Princeton Plasma lab). Three of the smaller labs —including the Solar Energy Research Institute (SERI)—are run specifically by DOE's Applied Energy programs. In general, the larger labs do some work for each of the three programs.

DOE labs are unlike nearly all the rest of the Federal labs, in that all except two of the smaller ones are operated by contractors (they are government-owned, contractor-operated, or GOCOs). Almost all other Federal labs are government-owned and government-operated (GOGOs). The contractors who operate GOCOS vary: some are profit-making, others non-profit; some are industrial firms like Martin Marietta, other are universities like the University of California. GOCOS face some specific problems of their own in the transfer of technology, as we shall see later.

DoD LabS

There are some 68 DoD labs, and DoD spent about $10.5 billion on lab R&D in 1989. These labs are run directly by the Departments of the Army, Navy, and Air Force.

Less is known publicly about the DoD than the DOE labs, partly for security reasons. However, the DoD labs have also been under increasing pressure to encourage commercialization of the technology that they develop. The Stevenson-Wydler Technology Innovation Act of 1980, the Patent & Trademark Amendments Act of 1980, and the Federal Technology Transfer Act of 1986 cleared legal barriers blocking transfers from these labs and promoted structural changes (like the delegation of key decisions) that would encourage transfer. Some DoD labs are clearly making a major effort in this field and others have historically worked well with the private sector. However, in October 1989 DoD's Office of the Inspector General published a report that was sharply critical of the extent to which the letter and spirit of the law had been implemented.[25]

Other Labs

NIH spends about $1 billion in Federal labs. All NIH labs but one are GOGOS. NIH has a good reputation for pushing its technology out toward the private sector and encouraging its scientists to do so.[26]

NASA spends about $2.5 billion in the Federal labs. All but one of NASA's seven labs are GOGOS. NASA's labs (and those of its predecessor, NACA) have been productive in collaborating with industry (see box 2-A). Some of NASA's lab work is still useful to civilian aircraft manufacturers, but its main focus today is the national space program.

NIST (the National Institute of Standards and Technology, formerly the National Bureau of Standards) sees its work with industry as part of its primary mission. NIST spends about$110 million in its labs. The NIST labs have long worked closely with industry in the areas of measurement, standards, materials science, and computer systems, and NIST's Center for Manufacturing Engineering (funded at about $6 million) follows the tradition.

This section concentrates mostly on DOE's nine national labs. They are big, they work on a variety of projects that could be of commercial interest, and information about them is readily available. For these reasons, the report uses an analysis of DOE's national labs to illustrate the problems and potential of the Federal labs as a whole. As discussed below, the light cast by the DOE national labs helps to illuminate the positions of other agencies and labs. While some might argue that DoD labs cannot be expected to follow the same path toward the commercialization of technology, there is evidence that the defense-oriented DOE labs provide some commercially important technology.

[25]U.S. Department of Defense, Office of the inspector General, *Report on the Audit of the DoD Domestic Technology Transfer Program, No.* 90-006 (Arlington, VA: U.S. Department of Defense, Oct. 19, 1989).

[26]The one area of special interest to manufacturing--biotechnology-is the subject of a separate OTA report, *Biotechnology **in a Global Economy,*** scheduled for release in late 1990.

Commercializing DOE'S Technology: Mechanisms

"Commercialization" here means making technology developed in the Federal labs useful in industry. In the past, that typically meant nothing more than the publication of research results in conferences and journals, after which the results would make their way to industry and eventually find application. Today, such delay is costly, as U.S. firms fall behind in applying the latest technology to manufacturing. In these changed circumstances, faster commercialization takes on more importance, and several useful mechanisms to promote it have emerged. Collaborative R&D is lab-industry teaming to create new technology for industrial use. Spin-offs and startups transfer already existing technology to existing and new firms respectively. Various mechanisms (e.g., personnel exchanges) can prepare the ground for either form of commercialization.

Collaboration

Collaborative R&D-planned, performed, and sometimes funded jointly by the labs and industry—is a powerful means of commercializing technology. It is not entirely new for the Federal labs: NIH and NIST, for example, have done collaborative work with industry for years.[27] However, it is not at all common in DOE's national labs; only 57 collaborative projects were under way in all national labs in 1987.[28]

Most of DOE's collaborative R&D has been carried out by its Applied Energy programs. These have sometimes targeted particular industries for ongoing R&D projects. This continuity allows the labs and companies to get well acquainted with each others' interests, abilities, and needs, and to smooth out ways of working together. For example, SERI, which has worked on solar energy applications for more than a decade, collaborated successfully with U.S. industry in an effort to catch up with Japan in the commercialization of amorphous silicon technology for solar cells. The SERI project lasted from 1984 to 1987 and had a 3-year budget of $19 million; four firms put up 30 percent of the funds. A second 3-year program, lasting through 1990, is now under way, and half of its $40 million funding is industry-supplied. In both programs, the firms are given patent rights and certain proprietary rights to data, enabling them to get a jump on the competition.[29]

DOE's HTS pilot centers, also run by Applied Energy, follow the targeting model. This experiment is discussed in box 7-B.

Until recently, DOE's Defense Programs viewed commercialization as a distraction from its mission of supplying the military's needs, but it has come to believe that the military would benefit from stronger civilian industries.[30] In 1989 it funded two lab-industry consortia for work on dual-use technologies (those having both military and civilian uses). One group, working to improve the quality of specialty metals such as nickel-based or titanium alloys, will use Sandia's specially instrumented research furnaces to monitor and control the production process. During 1989-94, government will provide $2 million and the collaborating companies will contribute $4.75 million. The industry share will increase steadily, rising to 100 percent after 5 years. The second consortium, the Advanced Manufacturing Technology Initiative, will work on next-generation manufacturing technologies such as advanced controller software and artificial intelligence. DOE has funded this project at $500,000 for fiscal year 1990, a level that will be maintained for four more years. DOE funds for the two projects rose from $400,000 in FY 1989 to $1.1 million in fiscal year 1990.

Several other lab-industry collaborations for dual use technologies are under consideration. These include projects on plasma destruction of toxic substances, combustion synthesis of ceramics, and ceramic metal composites. However, the two projects noted above will entirely exhaust Defense Programs' funds for such collaborations for fiscal year 1990.

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[27] U.S. General Accounting Office, *Technology Transfer: Implementation Status of the Federal Technology Transfer Act of* 1986, RCED-89-154 (Gaithersburg, MD: 1989), pp. 29-31.

[28] Energy Research Advisory Board, op. cit., p. 21.

[29] Ibid., pp. B5-B6.

[30] Military dependence on Civilian technology is discussed in U. S. Congress, Office of Technology Assessment, *Holding the Edge: Maintaining the Defense Technology Base*, OTA-ISC-420 (Washington, DC: U.S. Government Printing Office, April 1989).

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Box 7-B—DOE'S HTS Pilot Centers

As part of its research program in high-temperature superconductivity (HTS), the Department of Energy (DOE) started up HTS pilot centers at three of its national laboratories—Argonne, Oak Ridge, and Los Alamos—in October 1988.[1] These centers are planned as new ventures in lab-industry collaboration, a conscious experiment in rapid technology development and transfer.

Each center has government funding of $1,6 million for FY 1989 (total $4.8 million), and $2.0 million per center (total $6.0 million) is planned for FY 1990. In their first year of operation, the pilot centers negotiated 20 cooperative R&D agreements, with costs usually shared equally between the lab and industry. Industry was ready to join in many more projects than the centers could fund.

Several features of the pilot centers are designed to expedite technology transfer. First, the centers have a transfer-oriented mission and funds to accomplish that mission. The funds are spent only on projects requested by industry. The labs and industry plan to collaborate over the whole R&D cycle, from basic research through product development, with lessons from development fed back into research, Each center has an industry advisory board which DOE consults on the substance and procedure of lab-industry collaboration.

DOE has tried to speed up the negotiation process by offering a model collaboration contract, which carries automatic approval with changes requiring varying levels of clearance. At first, many firms found the model contract's terms unacceptable, but DOE has been revising the terms to meet the fins' objectives. DOE also agreed beforehand to waive rights to inventions made in pilot center research, to a greater extent than for cooperative R&D generally. Also, for work funded at least half by industry, DOE allows, on a case-by-case basis, the withholding of technical data from publication for up to 2 years. This delay, not generally allowed in DOE cost-shared research, can give the firm a valuable head-start in the market.

The HTS pilot centers experiment will be evaluated after 2 years. DOE is committed to applying the lessons learned to cooperative R&D in other programs,

[1] Los Alamos National Laboratory had recommended establishing these centers, when asked by DOE to study how to involve industry in developing HTS technology. John T. Whetten, associate director, Los Alamos National Laboratory, testimony at hearings before the House Committee on Science, Space, and Technology, Subcommittee on Energy Research and Development, July 27, 1988, Serial No. 100-122, pp. 90-91.

In some cases of lab-industry collaboration, DOE has put up all the money, with the private company acting essentially as a contractor. This was the case in the collaboration between Cray Research Corp. and Los Alamos National Laboratory. Cray pioneered the development of supercomputers. Its first and crucial customer was Los Alamos, which needed massive computing power to simulate the operation of weapons and nuclear power plants. Although Cray did most of the R&D and Los Alamos paid for it, the lab was more than a passive customer, spending several person-years studying Cray's machines and suggesting design changes to better suit the lab's needs. The lab's purchases were crucial to Cray's early survival. In 1976, when the company was on the verge of bankruptcy,[31] Los Alamos bought the first machine sold by Cray. By 1989, Los Alamos had bought 14 Cray machines, for a total price (net of trade-ins) of about $200 million.

Spin-Offs to Existing Firms

Lab work done for purely research or defense purposes sometimes turns out to have valuable commercial applications. Firms that make a point of staying in touch with the latest developments, in the government labs and elsewhere, can find out early about such promising research results and can adapt them to commercial purposes ahead of the competition. A firm's own engineers are in the best position to glean research results from outside labs, because they know their own product development cycle, and hence the best times for incorporating new ideas. However, monitoring the vast Federal labs system is difficult even for large firms and often impossible for smaller firms with more limited staff, Without help from the labs, they are not likely to benefit from spin-off. The labs can help in several ways.

[31] Cray had applied to the Securities and Exchange Commission in 1975 for permission to go public, but its application was rejected because SEC believed that there was no market for the Cray machine and the company would not survive.

Occasionally, DOE labs have encouraged spin-off by seeking out firms to apply the technology. For example, Los Alamos gave copies of its Common File System, software that lets different supercomputers share the same data, to several other government and commercial labs between 1980 and 1988. To ease the burden of supporting the software and also to reach a wider audience, Los Alamos found a private firm to develop the software into a commercial product, and in January 1989 concluded an exclusive licensing agreement providing for royalties and continued cooperation.[32]

Spin-off also takes place in less formal ways. Firms with technical questions often get modest amounts of free help from government labs. For example, Sandia receives 600 industry visitors per month and believes that its "free, helpful consultation" with industry is "probably the most productive and yet hard-to-quantify source of technology transfer by the laboratory."[33] For example, the lab has helped in designing high-pressure glass columns for liquid chromatography; assisted in testing the strength of metals; and provided manufacturers with new types of glass that it developed for sealing to metals.[34] Sandia staff even make house calls on occasion. In one plant visit, the lab staff showed a firm how to use new equipment to duplicate Sandia's superconductor fabrication process. This help, according to the firm, 'leaped us months ahead of schedule. '[35] In turn, Sandia staff also learn how their technology works in the field.

Startups

A lab's technology is sometimes commercialized not by an established firm but by a new firm started for that purpose. Startups often can get a new technology to market quickly and they may be more committed to the technology than established firms, but they may lack internal funding, experience in manufacturing, plant or equipment, and distribution channels. From 1985 to 1987, 87 startups were formed to commercialize technologies from DOE labs.[36]

Researchers may leave a government lab to head or work in the startups. Some labs encourage this by granting entrepreneurial leave, with the right to return to their old jobs within a stated time.[37] These labs see the movement of researchers into startup firms as a good way to commercialize technology quickly. However, some people are concerned that lab research teams could be depleted and also that labs might improperly favor their own researchers over established firms for commercializing the technology.

Some labs have gone farther in encouraging startups. The Tennessee Innovation Center (TIC) was formed in 1985 with $3.5 million from Martin Marietta Energy Systems, the operator of Oak Ridge National Laboratory .38 TIC provides numerous services to entrepreneurs, including office and lab space and help in forming business plans and incorporation. TIC typically contributes capital of $30,000 to $100,000 in return for a minority interest in the firm. Its stock in its most successful investment was worth about $7 million by June 1989.[39]

Another approach is offered by the non-profit ARCH Development Corp., formed in 1986 as an affiliate of Argonne National Laboratory and the University of Chicago. ARCH is given patent rights to virtually all inventions at Argonne and the University of Chicago.[40] It identifies those worth patenting, bears the expense of obtaining patents, and tries to license the inventions or, where it makes

32' 'General Atomics to Market Los Alamos Computer Software, ' Los Alamos National Laboratory Public Affairs Office, Jan. 26, 1989; Raymond Elliott, Computing and Communications Division, Los Alamos National Laboratory, personal communication, July 3, 1989.

33R. Geer, ''Technology Transfer Is a Process of Quiet Matchmaking, " *Lab News*, vol. 41, No. 12, June 16, 1989, p. 1; *Annual Report: Technology Transfer, Sandia National Laboratories, Fiscal Year 1987,* op. cit., p. 9.

34*Annual Report: Technology Transfer, San&a National Laboratories, Fiscal Year 1987,* op. cit., pp. 16, 23-25, 28-29.

35Letter from [author is confidential] t. Dr. Dan Doughty, Supervisor, Inorganic Materials, Chemistry Division 1846, Sandia National Laboratories, June 8, 1989.

36Energy Research Advisory Board, op. cit., p. 42.

37U.S. Department of Energy, *Technology Transfer Summary,* July 1988, p. 6; see also David Kramer, "Two Los Alamos Scientists Forma Spin-off To Develop New Cell-Probing 'Tweezers,'" *McGraw-Hill's Technology Transfer Report,* February 1989, p. 3.

38The funding in turn came from the management fee paid by DOE.

39Donald Jared, Program Administrator, Office of Technology Applications, Martin Marietta Energy Systems, Oak Ridge National Laboratory, personal communication, June 20, 1989.

40Since the University of Chicago, which operates Argonne, is a nonprofit organization, DOE waives its patent rights on request, with some exceptions. The waiver process is discussed later in this section.

good business sense, forms a startup firm itself to commercialize the invention. The startup's initial capital comes partly from a $9 million venture capital fund managed by ARCH, but ARCH usually waits to get additional capital from an unrelated party, as an objective check on the proposed company's worth. ARCH is seeking to replicate the environment at MIT and Stanford, which has done well in supporting startup fins. MIT, with its research budget of only $700 million and only seven professional staff working on patents and licensing, produces about the same number of licensing agreements and new firm startups as all of DOE's labs combined, with their government budget of more than $5 billion.[41] The success of MIT and Stanford owes much to the infrastructure of entrepreneurs, venture capitalists, business planners, lawyers, and bankers, which ARCH is seeking to replicate.

Other Forms of Technology Transfer

A common and relatively simple way of making lab technology available for commercial purposes is to let firms use the labs' specialized facilities. This is not a new idea. Before World War II the National Advisory Committee on Aeronautics made its wind-tunnels and other test facilities available to commercial aircraft companies, and NASA continued to do so after the war. Today, DOE's national labs allow private firms to use an array of expensive special-purpose facilities. In 1987, about 185 scientific facilities in the national labs were used by 1,623 industry and university participants.[42] As of March 1989, Brookhaven National Laboratory's two synchrotrons, set up as advanced X-ray sources, were being used by more than 80 American universities, 23 U.S. fins, 14 other government labs, and 22 foreign institutions.[43] The Combustion Research Facility at Sandia National Laboratories offers specialized lasers and computers for studying how fuels burn. Its users include General Motors, Ford, Chrysler, Exxon, Mobil, Conoco, Unocal, Combustion Engineering, AT&T, and GE.[44]

The Federal labs are also putting new emphasis on technology transfer in their formal communications—published papers, conferences, and so on. Several of DOE's national labs, for example, publish semi-technical brochures to acquaint industry with technologies which may be of interest. Meetings and workshops focused on technology transfer are increasingly common.

The Federal Laboratory Consortium (FLC), composed of representatives from Federal laboratories, also promotes communication with industry .45 The FLC guides firms into the Federal lab system, showing them where to go for help on a particular problem--often within a day or so of the initial inquiry. In conjunction with the Industrial Research Institute, the FLC held lab-industry conferences to identify possible areas of collaboration in manufacturing technology (in 1988) and in hazardous waste management (in 1989). The FLC also funds projects to demonstrate technology commercialization. For example, the University of Utah has a database on specific interests of high-technology firms, using it to market the University's own inventions. The FLC paid the university to adapt this database for experimental use by three Federal labs. Finally, the FLC, the Department of Commerce, and DOE all maintain computerized general-purpose databases on technologies of possible interest to industry. Some of the labs also maintain specialized databases, such as one on superconductivity at Oak Ridge National Laboratory.

Many of the mechanisms described above rest implicitly or explicitly on personal contact between lab employees and private industry, and indeed the exchange of personnel between labs and industry offers another mechanism for technology transfer. Lab researchers can take sabbaticals or visiting positions to spend time (perhaps a year or two) in an established company, and vice versa—with benefits both of immediately transferring information in both directions and developing personal contacts for the future. Such formal exchanges have been rare in the

41 John T. Preston, Director, MIT Technology Licensing Office, ''Creating New Companies and Business Units Within Existing Companies via University License Agreements, " presented to the European Venture Capital Association 1987, modified April 1989; Senator Pete V. Domenici, testimony at hearings before the Senate Committee on Energy and Natural Resources, Subcommittee on Energy Research and Development, May 11, 1988, Serial No. 100-602 (Part 2), pp. 3-4.

42 Energy Research Advisory Board., Op. cit., pp. 21, 61.

43 David Kramer, "For Hire: Lab Facilities," *McGraw-Hill's Tech Transfer Report*, March 1989, p. 1

44 Ibid.; *Annual Report: Technology Transfer, Sandia National Laboratories, Fiscal Year 1987*, op. cit., p. 8.

45 Originally established by the Defense Department in 1971, the FLC evolved as an informal coordinating group until it was given an official mandate by the Federal Technology Transfer Act of 1986 (see 15 U.S.C. 3710(e)).

national labs. In 1987 just 19 industry researchers came to them, and 4 lab scientists went to companies, in an exchange program underwritten by DOE. However, about 400 more industry scientists and engineers worked less formally at the national labs at some time in 1987, using funds from industry and DOE R&D programs. Lab researchers can also serve as consultants to industry-a practice that increased in the 1980s (from 266 consulting projects in 1981 to 697 in 1987).[46]

Barriers to Technology Transfer

A number of factors limit the Federal labs' transfer of technology to industry. There are problems related to the labs' historical mission, the bureaucracies that run the labs and supervise them, and the nature of technology transfer itself (especially in the area of exclusive rights). Industry itself is not blameless: for example, both U.S. universities and foreign corporations send more visitors to the labs than does U.S. industry .47

Mission--The lion's share of DOE labs' funding comes through the Defense and Energy Research Programs. For these programs, commercialization tends to be low priority. In contrast, DOE's Applied Energy projects are usually planned with commercial application as an integral part of their mission, and it is on the whole accomplished effectively. However, Applied Energy has a small and declining share of DOE lab funding.

Funding-Technology transfer does not come cheap. Identifying technologies with commercial possibilities, finding firms that might be interested, and exchanging information with those firms take time and effort, but are necessary parts of aggressive technology transfer. Negotiating terms with firms interested in licenses—and fighting through red tape back at the lab or agency—takes still more effort, indeed probably requires some full-time technology transfer staff. Encouraging startup firms can also be expensive. Patenting is also expensive, especially outside the United States. And if the labs go in for collaborative R&D projects with industry, the labs' share must be funded--often a a level greater than could be justified by the labs' defense or basic research missions.

On the whole, DOE's technology transfer effort has been underfunded. Collaborative R&D has rarely been funded outside the Applied Energy programs and technology transfer offices have been thinly staffed. DOE is not alone in this. DoD, for example, has required its labs to fund technology transfer activities out of overhead.[48]

Lab directors and agencies can hardly be expected to embrace technology transfer enthusiastically if they have no money to pay for it, or have to rob Peter to pay Paul. Low spending is also a signal. Skimpy funding leads companies to question the labs' commitment.[49] Dependability is important too. Delays in expected funding have caused industry to view the labs as unreliable collaborators.[5o] In addition, firms may hesitate to pledge themselves to multi-year projects when the government will commit funds only year by year.

Incentives—Incentives for collaboration in the labs are sometimes weak or even negative. Time spent answering a fro's questions is usually time spent away from research; and help to industry does not always count in a researcher's performance evaluation, even though the law specifically directs

46Energy Research Advisory Board, op. cit., pp. 21-22. Only 45 industry researchers visited the DoD labs in 1986, while 291 visited the much smaller NIST (then called NBS) labs; U.S. General Accounting Office, Technology Transfer: U.S. and Foreign Participation in R&D at Federal Laboratories, RCED-88-203BR (Gaithersburg, MD: U.S. General Accounting Office, 1988), p. 20.; Rees L. Dwyer, III, Executive Assistant to the Assistant Secretary, Management and Administration, Department of Energy, personal communication, Jan. 4, 1990.

47David Kramer, "Trivelpiece: Visits Give Rise to Tech Transfer," *McGraw Hill's Tech Transfer Report,* March 1989, p. 5.

48U.S. Department of Defense, Office of the Inspector General, Report on the Audit of the DOD Domestic Technology Transfer Program, Report No. 90-006, Oct. 19, 1989, pp. 8-9.

49John Whetten, acting director, Los Alamos National Laboratory, testimony at hearings before the House Committee on Science, Space, and Technology, Subcommittee on Energy Research and Development, July 27, 1988, Serial No. 100-122, p. 90.

50William Black, Jr., Senior Vice President, Biomagnetic Technologies Inc., testimony at hearings before the HousCommittee on Science, Space, and Technology, Subcommittee on Energy Research and Development, June 23, 1988, Serial No. 100-118, pp. 79-80; William Gallagher, manager, Exploratory Cryogenics, Thomas J. Watson Research Center, research division, International Business Machines Corp., testimony at hearings before the House Committee on Science, Space, and Technology, Subcommittee on Energy Research and Development, June 23, 1988, Serial No. 100-118, p. 156; Harold Hubbard, Director, Solar Energy Research Institute, testimony at hearings before the House Committee on Science, Space, and Technology, Subcommittee on Energy Research and Development, July 27, 1988, Serial No. 100-122, p. 97.

that it should.[51] Collaborations with industry maybe unattractive if the work is proprietary and the researcher cannot publish his results. In addition, time that researchers spend on sabbatical in industry is often not counted as pensionable.

Recently, researchers and their labs have been permitted to keep portions of patent royalties paid for their inventions. While the amount of money is often modest, it does offer recognition for work that is useful to industry .52 Some agencies and labs provide added incentives. At least one lab (Oak Ridge National Laboratory) sets aside an extra 4 percent of royalties to reward lab researchers other than those named as inventors on licensed patents for extraordinary contributions to technology transfer.[53]

Slow ***Negotiations--Speedy*** negotiations for licensing of technology, and also for collaborative R&D (which typically includes licensing provisions), are important to fins. They have to fit innovations into their product development schedules and hold on to earmarked funding (their own or investors'). Delays can cause deals to collapse as the firm's strategic situation changes, or the people involved move on. Startups are especially vulnerable.

Negotiations with labs can often take many months. Some delay may be hard to avoid but some is caused by bureaucratic slowness and government reluctance to grant exclusive rights. Both are largely avoidable. Reviews by agency headquarters that convert two-way negotiations between a lab and a firm into three-way negotiations have often been the culprit.[54] For GOGO labs, agency review of collaborative R&D agreements was in principle short-circuited by the Federal Technology Transfer Act of 1986[55] and an Executive Order in 1987,[56] which respectively permitted and required agency heads to delegate to lab directors the authority to negotiate collaborative R&D agreements, subject to agency veto within 30 days. However, many agencies have been slow to implement this delegation.[57] Moreover, these provisions did not apply to DOE's GOCO labs. After complaints by labs and industry about DOE red tape, Congress in November 1989 amended the law to permit similar delegation of authority to GOCO labs.[58] DOE will probably make such a delegation.[59]

Exclusive Rights—Many delays revolve around the companies' desire for exclusive rights, to help recover the cost of expensive R&D efforts. Exclusive rights may also carry certain social costs, including higher prices and reduced use of the technology by others.[60] These costs and benefits must be balanced case by case.[61] This sort of decision might be made by the labs themselves, subject to agency guidelines and audits. However, in many cases the labs' hands are tied.

51The Federal Technology Transfer Act of 1986 directs lab directors to "ensure that efforts to transfer technology are considered positively in . . . evaluation of. . . job performance." 15 U.S.C. 3710(a).

52The Federal Technology Transfer Act of 1986 allows researchers in GOGOs to collect 15 percent of the royalties from their patents, Up to $100,000 per year. Many agencies, including DoD, voluntarily give inventors a greater share. The lab gets much of the rest. Many of DOE's GOCO labs also give the inventors a share of patent royalties. U.S. Congress, General Accounting Office, Technology *Transfer: Implementation Status of the Federal Technology Act of 1986,* op. cit., pp. 37-38; Energy Research Advisory Board, op. cit., p. 44; U.S. Department of Energy, *Technology Transfer Summary,* July 1988, p. 5.

53Clyde Hopkins, President, Martin Marietta Energy Systems, Inc., testimony at hearings before the House Committee on Science, Space, and Technology, Subcommittee on Energy Research and Development, Mar. 25, 1988, Serial No. 100-136, p. 45.

54Joseph Allen, director, Office of Federal Technology Management, U.S. Department of Commerce, personal communication, Mar. 9 and 21, 1989.

55See 15 U.S.C. 3710a. This authority applies only to projects in which the lab contributes only personnel, services, facilities, equipment or other in-kind resources; the lab cannot pay money to its industrial partners.

56Executive Order 12591, Apr. 10, 1987.

57U.S. Congress, General Accounting Office, *Technology Transfer: Implementation Status of the Federal Technology Transfer Act of 1986,* op. cit., pp. 23-30; U.S. Department of Defense, Office of the Inspector General, op. cit., p. 10.

58National Competitiveness Technology Transfer Act of 1989, Public Law 101-189, Sec. 3133 (amending 15 U.S.C. 3710a).

59DOE had previously supported a bill which would have made such delegation mandatory for the national labs. (The bill was not enacted.) Letter from John Herrington, secretary, U.S. Department of Energy, to Senator Pete Domenici, Sept. 28, 1988, supporting S. 1480, as reported in Senate Report No. 100-544, Sept. 23, 1988. See Sec. 205.

60These costs and benefits apply to intellectual property protection (patents, copyrights, trade secrets) in general, not just in lab-industry agreements; see the section below entitled Intellectual Property,

61Exclusive rights can often be limited to a particular application of the technology. For example, an engine manufacturer might be given the exclusive right to use a patented alloy ***in engines,*** but be given only a nonexclusive right, or no right at all, to use the alloy in other products.

- *Patents.* In order for DOE labs to give firms patent rights, DOE must generally first waive those rights. In the past few years, labs have experienced long waits in obtaining waivers. It appears that it typically took 6 to 12 months from the lab's application until DOE approval. In early 1989 DOE's patent counsel worked to eliminate any backlog of applications over 6 months old, but the waiting times have again grown longer pending resolution of policy issues. Some labs have complained about the paperwork DOE requires for waivers. DOE's view has been that it is required by statute to consider certain factors in granting waivers.[62]

  In the Bayh-Dole Patent Amendments Act of 1984, Congress tried to cut this red tape for DOE's labs with non-profit operators. The Act provided that, with certain exceptions, these labs need not apply for waivers but can simply claim the right to government-funded inventions.[63] Congress specifically exempted inventions that are classified for security reasons (for which DOE rarely if ever grants waivers anyway), and also unclassified inventions at defense-oriented labs that relate to weapons or naval nuclear propulsion. Congress also permitted DOE to exempt other inventions under "exceptional circumstances."[64] After DOE implemented this provision in its operating contracts with these laboratories,[65] DOE had disagreements with the Commerce Department and the University of California over the proper scope for DOE's 'exceptional circumstances" exemption.

  DOE has supported extending the Bayh-Dole approach to national labs with for-profit operators,[66] and also to unclassified weapons inventions unless they are designated as sensitive technical information-all subject to guidelines and safeguards such as restricting the use the operator may make of royalties.[67] However, this legislation was not enacted.

- *Proprietary Rights.* The right to keep data proprietary may be as important as patent rights to firms. Until recently, the Freedom of Information Act (FOIA) was a major obstacle, at least calling into serious question an agency's ability to keep secret the results of collaborative R&D. This discouraged firms from participating.[68] However, Congress recently largely removed this obstacle, exempting the results of collaborative R&D from release under FOIA for 5 years-usually enough time to get a head start in the market.[69] DOE's organic statute (the provisions that set up DOE and its predecessor agencies) provides that DOE should not hinder the dissemination of technical data.[70] The courts have not ruled on how this might apply to results of collaborative research. DOE believes that the Act might apply, but only to data actually in the custody of DOE or the lab.

- *Copyright of Software.* Firms that develop government software into a commercial form or who collaborate with the government to create software are also likely to insist on exclusive rights. Often secrecy is not practical, as software can be duplicated once it exists. Copyright could provide effective protection. However, it is generally not possible in collaborations with or licenses from a GOGO, because material developed in whole or part by govern-

[62] The law instructs DOE t. follow the goals of promoting Commercialization, fostering competition, making the benefits of R&D widely available in the shortest possible time, and encouraging fiis' participation in DOE research, and to consider such factors as the firm's investment, ability to contribute to research or commercialization, and the need to grant rights as an incentive to participation. See 42 U.S.C. 5908.

[63] 35 U.S.C. 202(a). Although AT&T Technologies, the AT&T subsidiary that runs Sandia, takes no management fee, it is considered a for-profit firm for this purpose.

[64] 35 U.S.C. 202(a); see also 35 U.S.C. 200.

[65] See Energy Research Advisory Board, Op. cit., p. 49.

[66] These include Martin Marietta Energy Systems, Inc., which operates Oak Ridge; AT&T Technologies, which operates Sandia; and EG&G Idaho, Inc., Westinghouse Idaho Nuclear Co., Inc., and Rockwell-INEL, which operate Idaho National Engineering Laboratory.

[67] Letter from John Herrington, secretary, U.S. Department of Energy, to Senator Pete Domenici, Sept. 28, 1988, supporting S. 1480, as reported in Senate Report No. 100-544, Sept. 23, 1988. See Sees. 207,209.

[68] U.S. Congress, General Accounting Office, *Technology Transfer: Implementation Status of the Federal Technology Transfer Act of 1986*, op. cit., p. 49; US. Congress, General Accounting Office, *Technology Transfer: Constraints Perceived by Federal Laboratory and Agency Officials*, op. cit., pp. 15-17.

[69] National Competitiveness Technology Transfer Act of 1989, Public Law 101-89, &x. 3 133(a)(7) amending 15 U.S.C. 3710a.

[70] The law states, for example, that arrangements for conducting research shall not "contain any provisions or conditions which Prevent the dissemination of scientific or technical information except to the extent such dissemination is prohibited by law. " 42 U.S.C. 2051.

ment employees is not copyrightable.[71] Hence, officials at several labs and agencies favor changing the law.[72]

This problem does not arise in GOCO collaborations, since GOCO lab staff are not government employees. However, DOE initially permitted firms to copyright software created partly by a lab only if the firm agreed to deposit the source code for public inspection—which firms were sometimes unwilling to do. In 1989, DOE changed its policy to permit fins, on a case-by-case approval, to make public only an abstract of the software.[73]

Additional Concerns—Even if labs and parent agencies make it a part of their mission to put government research at the service of industry, and if they get funds for the purpose, other concerns still can stop efforts to promote commercialization unless a strong voice within the agency favors such efforts. Moreover, balancing other concerns, such as U.S. national security, against the benefits of commercialization is likely to require intra- and interagency coordination and indeed Presidential leadership.

One concern is fairness. In offering licenses to technology and opportunities for collaborative work, labs and parent agencies try to avoid favoring particular fins. The practical matter of avoiding lawsuits or complaints to Congress is involved, as well as the ethical issues of fairness. But attempts to be fair can slow commercialization.[74]

Also, lab-industry collaboration has the potential for conflicts of interest. For example, the collaborating lab researcher may also have done private consulting for the firm, may have once worked for the firm, or may seek royalty payments for himself or the lab from the firm. Guarding against conflicts of interest takes careful planning and judgments. Agencies without a strong commitment to technology transfer might prefer to avoid the whole problem.

Some labs, such as NIH, place a high value on free exchange of ideas within the lab and with people outside. This poses problems for collaborations involving proprietary research with industry .75

National security needs may also clog the free flow of information out of the labs. In response to this problem, DOE's Defense Programs office assigned responsibilities for information security and technology transfer to the same staff, thus helping to ensure that the two concerns are fairly balanced. Sandia did the same.[76]

Finally, there is the tricky double problem of defining a U.S. firm and determining Federal lab policy toward non-U.S. firms.

General Applications

The **story** of the DOE labs has implications for all the Federal labs, despite the differences among them. One is simply that technology transfer can be done. There are some success stories from DOE, most of them rather unpublicized. Technologies did emerge from the labs and were exploited by U.S. fins, often with help from the labs. On the other hand, the story also suggests that even the DOE labs, which have faced considerable congressional scrutiny on this issue in recent years, have a long way to go in improving their performance.

The HTS pilot projects illustrate both sides of the story. DOE took significant steps forward in setting up the projects and committing to apply the lessons that may emerge from them to other lab programs. However, the process is likely to be a slow. The experiment lasts ***2 years,*** evaluation will take time, the development of DOE-wide policy will take longer, and implementation of that policy will take longer still. This is in the nature of the beast, and DOE should not be faulted for working methodi-

[71] 17 U.S.C. *105,* 101.

[72] U.S. Congress, General Accounting Office, *Technology Transfer: Implementation Status of the Federal Technology Transfer Act of 1986,* op. cit. > pp. 48-49; U.S. Congress, General Accounting Office, *Technology Transfer: Constraints Perceived by Agency Officials,* op. cit., pp. 11-12.

[73] According t. DOE's counsel, it is possible that a court would nevertheless compel disclosure of the entire source code under the DOE's organic statute. Richard Constant, Assistant General Counsel for Patents, U.S. Department of Energy, personal communication, Feb. 23, 1989. However, DOE's position is that publication of the abstract satisfies the agency's dissemination requirement.

[74] U.S. Congress, General Accounting Office, *Technology Transfer: Implementation Status of the Federal Technology Transfer Act of 1986,* RCED-89-154 (Gaithersburg, MD: May 30, 1989), pp. 49-50. In general, collaborative R&D agreements contracts are not subject to the stringent fairness requirements of government procurement contracts.

[75] U.S. Congress, General Accounting Office, *Technology Transfer: Constraints Perceived by Agency Officials,* op. cit., p. 17.

[76] *Annual Report: Technology Transfer, Sandia National Laboratories, Fiscal* Year 1987, op. cit., p. 9.

cally. However, the process could easily take 4 to 5 years-the equivalent of two generations of products in some high-technology sectors.

Attitudinal barriers need to be further dismantled as technology transfer becomes an organic element of most programs, rather than remaining the province of isolated specialists or even special programs (like Applied Energy at DOE). Commercialization needs to be supported with funding, which includes funds for appropriate people. For example, the recent Inspector General's report on the DoD labs highlights the paucity of patent lawyers, leading to a backlog of applications and hence of technology transfers that cannot be made until applications have been filed. Legal obstructions need to be addressed, such as the problems surrounding software copyrights and DOE's ability to maintain proprietary information. Also, authority must be delegated to levels low enough to get the job done. DOE's labs have suffered long delays at agency headquarters and, according to the Inspector General's report, the DoD has not delegated sufficient authority or given policy guidance to a low enough level in the DoD hierarchy.

There are many reasons-financial, legal, practical, and philosophical-why the gears still grind slowly in bringing new technologies out of Federal labs and into manufacturing companies. It is much easier for both labs and parent agencies to go on doing things the traditional way than to tackle new problems in government-industry interaction— such as justifying extra funding for technology transfer, wrestling with conflict of interest issues, or negotiating collaborative research. It is also evident that real difficulties stand in the way of making the necessary changes. The labs' success in transferring technology will depend very much on funding for this purpose and on the will and attitude of senior lab managers and top officials of parent agencies, along with continued leadership from Congress and the President.

ENGINEERING RESEARCH CENTERS

The idea of creating university-based, multidisciplinary engineering research centers (ERCs) came out of discussions in 1983 between the National Science Foundation (NSF), the National Research Council, and the President's Office of Science and Technology Policy.[77] It was hoped that these center% would help the performance of U.S. industry by strengthening some of the weak links in American engineering: the link between engineering education and the real world of manufacturing, the link between university engineering research and industry engineering problems, and the links between the engineering disciplines.

NSF began to setup the program in 1984, and by 1988 had funded 18 ERCs at an average of about $2 million per center annually .78 (Box 7-C lists the ERCs and their areas of research.) The NSF funds cover about half the costs. Industry contributes about one-third, and the rest comes from university, State, and local finds. Each center gets NSF funding for an initial 5-year period, with a review after the third year. If the evaluation is positive, the ERC gets 5 more years of funding, starting with year four. Another review after the sixth year leads (if it is positive) to a final 5 years' funding from NSF—a total of 11 years, after which the ERC has to compete for new funds with proposed centers or else find some other source of money.

For an innovative n-year program that was deliberately planned with a long time horizon, it is too early to draw definitive conclusions about the program's success in meeting its goals. A few observations based on experience so far are in order.[79]

Overall, the centers have attracted impressive levels of financial support and participation from industry—a crucial element in their success. Individual centers get from 9 to 61 percent of their funding from private companies, and about 420 companies are taking part. However, most of the

[77] Much of the material in this section is drawn from Philip Shapira, "The National Science Foundation's Engineering Research Centers: Changing the Culture of U.S. Engineering?" contract report to the Office of Technology Assessment, March 1989. Additional material is drawn from David Sheridan, "The Engineering Research Centers," contract report to the Office of Technology Assessment, June 1989.

[78] In January 1990 three more ERCs were established.

[79] These observations are based on interviews with NSF officials, and site visits to ERCs at four universities, including interviews with faculty members, students, and industry participants in the ERCS. The universities were Carnegie-Mellon, the University of Illinois at Urbana, the University of Maryland, and Purdue. For more details of the visits and interviews, see Philip Shapira, op. cit.

Box 7-C—The National Science Foundation Engineering Research Centers

In June 1984, the National Science Foundation (NSF) invited proposals for the creation of Engineering Research Centers (ERCs). The Foundation received *142* proposals from over 100 universities. Six centers were selected in 1985:

- Columbia University, telecommunications
- Massachusetts Institute of Technology, biotechnology process engineering
- Purdue University, intelligent manufacturing systems
- University of California-Santa Barbara, robotics systems in microelectronics
- University of Delaware, composites manufacturing
- University of Maryland/Harvard University, systems research

Another round of 102 proposals was evaluated in 1986; NSF awarded five additional ERCs:

- Brigham Young University, University of Utah, advanced combustion
- Carnegie-Mellon University, engineering design
- Lehigh University, large structural systems (for construction)
- Ohio State University, net shape manufacturing
- University of Illinois, compound microelectronics

In 1987 three more centers were designated:

- Duke University, emerging cardiovascular technologies
- University of California-Los Angeles, control of hazardous wastes
- University of Colorado/Colorado State University, optoelectronic computing systems

in the fourth round, 1988, four more centers were awarded:

- North Carolina State University, advanced electronics materials processing
- Texas A&M University, University of Texas-Austin, offshore technology for recovery of oil and other resources
- University of Minnesota, interracial engineering
- University of Wisconsin—Madison, plasma-aided manufacturing

In 1988, the third year review of the first generation of ERCs resulted in decisions to phase out two centers-Delaware and Santa Barbara--over the following 2 years. The other four original centers were continued for another 5 years.

And in January 1990, three more centers were added:

- University of Montana, interracial microbial proves engineering
- Mississippi State University, geometrically complex field problems
- Carnegie-Mellon University, data storage systems center

companies are large (over 500 employees). The program does not reach many small or medium-size firms.[80]

Industry participation ranges from short-term help with specific problems, to recruitment of well-trained engineering graduates, to collaborations in long-term strategic research (e.g., several firms are participating in the optoelectronics program with the two Colorado universities, as a way of getting into future generations of semiconductor manufacture and application). The centers that have been in operation for more than a couple of years can all cite specific examples of technology transfer to industry. For instance, an advanced engineering design system developed at the Carnegie-Mellon Center is now being used by General Motors. Most of the technology transfers so far. though, have tended to be highly specific technologies. For example, a performance analysis workstation developed at the University of Maryland center has been commercialized by AT&T-SUN. NSF hopes that the centers will develop ‘‘whole new technology systems rather than pieces of systems. ’

[80] An exception is MIT's biotechnology program, In this field, many of the leading companies are small

While comments by industry representatives on the ERCs were nearly all favorable, observations by university faculty members on industry's involvement were more mixed. Many faculty members emphasized that contacts with industry had a positive influence on their own research, and that the program had established new relationships or enriched existing ones. On the other hand, some faculty members criticized industry's short-term outlook and unstable participation. Some (not all) companies seemed interested only in getting immediate answers to particular problems and avoided risky or long-term research. More generally, ERC faculty were concerned about the constant turnover of industry representatives, which obliges them to keep training new industry people. Said one: 'There is a constant educational process. '

The evidence so far shows the ERCs are making good progress in educating engineers in new ways. They are giving students opportunities to work with industry while they are in training; exposing them to an array of engineering disciplines and methods; giving them access to sophisticated research facilities; and fostering an interest in manufacturing. ERC graduates seem to have little trouble finding jobs, and in several cases corporate sponsors have actively recruited students before they graduated. Some of the students fear, however, that they will not be properly recognized by industry since their education has broken the mold of traditional disciplinary boundaries.

The number of students affected by the program is still small. In most of the universities with ERCs, only about 1 percent of engineering undergraduates are taking part in the ERC program (MIT, with nearly 14 percent undergraduate participation is a notable exception); between 2 and 14 percent of engineering graduate students in universities with ERCs are participating. And only 18 of the 280-plus U.S. colleges and universities offering engineering education have ERCs.

The ERCs have far less funding from NSF than originally planned, and this has caused problems for some of the centers. Individual ERCs are getting $300,000 to $1 million less per year than expected. Some have been able to makeup the difference from industry contributions, but others have had to reduce the scope of research and cut funds for equipment and students. One ERC director said that the shortfall in funding had curtailed efforts to build relationships with smaller businesses, and forced him to spend more time in fund-raising and less in research. It is possible that the industry share of ERC funding will continue to rise. However, companies tend to emphasize short-term projects, and their support over the long term is uncertain. In a survey by the General Accounting Office of companies sponsoring ERCs, 85 percent of respondents said they would continue support for the following year, but only 41 percent were willing to commit support 4 years in the future. Thus, it is likely that with greater industry funding would come less stability and more pressure for short-term results.

The ERC program is mostly at the research end of the R&D spectrum in industry. Whether it will lead to successful commercialization of new products or manufacturing processes is unknown. On this point, there is some skepticism within the program itself. As one ERC program manager with NSF said: "I think the ERCs will make clear the next generation of technology systems in their particular areas of research, but who in the United States will be capable of manufacturing those new technologies?' A faculty member at the University of Illinois ERC said: "It will be Sony, Toshiba, and other Japanese companies that will commercialize it. '

Possibly the ERCs' biggest impact on industry will be the caliber of the engineering students turned out. ''When they move into industry," said one NSF official, "those engineering students will be well prepared to take on the engineering problems of industry in a real world industrial context. " He added: "I look for them to move into management eventually where they will make their greatest contribution. About half the managers in Japan have a technical background, but the proportion in the U.S. is much lower. I'm hopeful the ERCs will play an important role in correcting this imbalance. '

TAPPING INTO JAPANESE TECHNOLOGY

Until recently, U.S. industry gave rather scant attention to research results and new technologies developed in Japan, for several reasons. First, many people in U.S. industry were hard to convince that Japanese technology had much to offer. This skepticism is now rare. Second, much of the Japanese superiority stems from excellence throughout the manufacturing process, and this involves things that are hard to copy. It is no easy matter to imitate a

whole interrelated system of organizing work and managing people. However, many U.S. managers are trying to adopt various aspects of Japanese manufacturing practice, and some are making headway.

Today, interest in Japanese technology goes beyond the factory into the laboratory. Japanese engineers and scientists are adding strength in research to their proven abilities to adopt foreign technologies and improve on them. Thus, keeping up with research results from Japanese labs is taking on new importance.

People-to People Technology Transfer

The Japanese have long been adept at keeping up with foreign scientific and technological research by sending people to study in other countries. For years, a great many Japanese scientists and engineers have undertaken graduate studies in American universities, attended scientific meetings in the United States, visited U.S. national laboratories, and won fellowships in U.S. Government laboratories. But the flow has mostly been one way. For example, in 1988 there were over 6,700 Japanese scientists and engineers working in U.S. Government and university facilities. The number of Americans working in Japanese labs was probably 800 at most.[81]

Several factors account for the meager presence of technically trained Americans in Japan. First, U.S. engineers have not been particularly eager to work in Japan. Not many speak Japanese and until quite recently, few were interested in learning it. For those engineers and scientists who do want temporary assignments in Japan, high living costs and the difficulty of finding jobs for spouses are other important obstacles. Moreover, very few U.S. companies or institutions have wanted to send technical people to Japan for extended stays, nor do they especially reward scientists and engineers who have experience in Japan. For example, MIT graduate engineers who take MIT-sponsored internships in Japanese Government, industry, or corporate labs usually find on their return that they are hired on much the same terms as engineers with no Japanese experience or Japanese language.[82] However, the personal relationships the interns form in their year or two in Japan may prove of great importance over the years in learning about the latest Japanese advances in technology. One company manager said that these young people may well turn out to be the industry leaders 25 years later.

The nature of Japanese institutions also deters U.S. researchers from doing work there. Much R&D in Japan—including some of the best—takes place in private industry, and since a good deal of this work is proprietary, acceptance of outsiders in corporate labs can be difficult. In government and university labs, the quality of basic research has been uneven, very good in some fields but less so in others. Furthermore, foreign researchers' access to government labs was rather limited until recently. In the United States, university and government labs have the reputation for consistently high-quality work. Positions in the United States interest foreign researchers, and foreigners are generally welcome. Japanese scientists win many of these positions on merit, often drawing stipends from the U.S. Government.[83]

Since 1962, the United States and Japan have had bilateral exchange programs in the field of science and technology. The U.S.-Japan Cooperative Science Program, established by executive agreement that year, has supported hundreds of joint seminars and short-term cooperative research projects ever since. In the late 1980s emphasis in these bilateral exchanges shined to longer term projects and more research by American scientists and engineers in Japan. A new agreement signed in 1988 reflected this changed emphasis.[84]

[81] National Science Foundation, Statistical Research Services.

[82] Under its Japan Science and Technology program, the Massachusetts Institute of Technology has sponsored 1-or 2-year internships in Japan since 1983. Returning interns reported to an OTA-MIT workshop in 1988 that, while employers took a positive view of the interns' Japanese experience, they were not always interested in making immediate use of that experience, or able to do so. Representatives of American companies that support the MIT program confirmed the point; the interns are treated like other newly hired engineers and are expected to fit into existing patterns of work assignment and rewards. (U.S. Congress, Office of Technology Assessment, *Technology Transfer to the United States: The MIT-Japan* ***Science and Technology Program,*** background paper, April 1989).

[83] For example, 327 Japanese did research at the National Institutes of Health in 1986-87, compared to 72 West Germans and 68 French. Stipends for five out of six Japanese werepaid by the NIH, at a cost of $6,8 million; fewer than half of the Germans and two-thirds of the French got NIH stipends. See Marjorie Sun, "Strains in U.S.-Japan Exchanges," ***Science,*** July 31, 1987.

[84] The Agreement Between the United States of America and Japan on Cooperation in Research and Development in Science and Technology, first signed in 1980 and revised in 1988.

One goal of the U.S. negotiators in the new agreement was "equitable contributions and comparable access to each Government's research and development systems."[85] In 1988, the Japanese Government established two award programs to bring as many as 100 young (under 35) post-doctoral or master' s-degree American scientists and engineers to Japan each year for research lasting 6 to 24 months. Placements are in university and government labs, some of which rank as world leaders (e.g., the Institute for High Energy Physics at Tsukuba). The awards pay for airfare to Japan, travel within Japan, a stipend, housing and family allowances, medical insurance, and Japanese language instruction. Each award is worth about $50,000 per year; 100 awards would amount to about $5 million per year.

In addition to founding these two programs, the Japanese Government also made a one-time gift of $4.8 million in 1988 to enable U.S. investigators to do research in Japan.[86] The National Science Foundation administers the fund, using it mostly for long-term visits for U.S. researchers (of any age, not limited to post-docs) in all kinds of Japanese labs—university, government, or corporate-with whom NSF concludes agreements. For example, NSF has an arrangement with the Japanese Ministry of Industry and International Trade (MITI) to offer U.S. applicants up to 30 research spots per year in the 16 laboratories directed by MITI's Agency of Industrial Science and Technology.

NSF also provides awards covering tuition, fees, and a stipend for researchers undertaking intensive study of the Japanese language. The program is primarily for graduate or post-doctoral scientists and engineers, but is also open to senior researchers, including people in industry; it can accommodate about 50 people per year. In addition, NSF supports programs at four universities to improve the teaching of Japanese, and about 50 more individual students get tuition and stipend awards in connection with these programs. Altogether, NSF set aside $800,000 in fiscal year 1988 for its Japanese Initiative programs, and $725,000 in 1989; spending in 1990 is expected to stay at the 1989 level. Most of the NSF funds are spent for bilateral seminars, short-term visits, and the Japanese language programs.

In late 1989, NSF spokesmen said that the Japanese language programs were oversubscribed and ''competitive, '' and that qualified people are being turned down. Participation in the new programs for long-term visits and research in Japan was spottier. NSF estimated that of the 100 places available from April 1989 to March 1990 in the two Japanese Government programs, about 60 to 65 would be filled. NSF's own program supporting long-term visits to Japan has had 18 participants since May 1988, but some seemingly attractive spots have had few takers. For instance, only one of the 30 slots offered in the MITI labs was occupied in 1989. None of a possible three posts in the Fifth Generation project was filled (one was the previous year). Only one researcher so far has been posted to a Japanese corporate lab.

The reasons mentioned above—the high cost of living in Japan and ignorance of the Japanese language—are still important deterrents to many potential candidates. The age limitation may be another; American researchers find it easier to take a year abroad when they are already established in academic or research positions than when they are just starting out. But a major factor may be unfamiliarity. These programs are barely more than 1 year old. As their reputations grow, they could fill up, as have some of private programs that sponsor placement of U.S. engineers and scientists in Japan. One of these is the Japan Science and Technology Program of the Massachusetts Institute of Technology, which sends MIT graduate engineers and scientists to corporate, government, or university labs in Japan for 1- or 2-year internships. In its first 6 years, 1983-89, the MIT program had 53 participants (an average of fewer than 10 per year). In 1989-90, it sent 47 interns to Japan.

Even assuming fairly rapid growth, all these programs together, public and private, will send only a few hundred researchers to Japan per year. Adding in those who go on their own, the numbers are still small compared with the thousands of Japanese

[85] Letter from the Honorable George P. Shultz, Secretary of State of the United States of America, to His Excellency, Sousuke Uno, Minister for Foreign Affairs of Japan, June 20, 1988; letter from Mr. Uno to Mr. Shultz, June 20, 1988. See also the Omnibus Trade and Competitiveness Act of 1988, which directed that federally supported international science and technology agreements should ensure "equitable and reciprocal" access to technological research, to the maximum extent practicable (Public Law 1O(M18, Part II, Sec. 5171, ''Symmetrical Access to Technological Research").

[86] The gift was arranged by then Prime Minister Takeshita.

scientists and engineers who study and work in the United States. Moreover, relatively few Americans in other fields related to industry and technology—economics, business administration, current business experience-spend time in Japan acquainting themselves with Japanese management and business practice. A few university programs (e.g. Stanford's) encourage exchanges of this kind by offering intensive training in the Japanese language.

Scanning Japanese Technical Literature

U.S. acquaintance with written research results from Japan does not begin to match Japanese knowledge of U.S. research. One reason is the idea, still current in some companies, that anything important will be published in English.[87] A more important reason is the scarcity of technically trained Americans able to read Japanese. Companies that want to keep up with Japanese research often cannot find someone to do it.[88] Job-seekers who offer this skill may be highly valued. For example, one American specialist with experience in scanning Japanese journals, translating titles and abstracts, and using on-line Japanese databases was hired by a high-technology company that told her to name her own price. The experience of this information specialist contrasts with that of the MIT engineers returning from Japanese internships, whose experience in Japan and knowledge of Japanese were usually not much used or specially rewarded in their first jobs back home. Companies may set a higher value on knowledge of Japanese in a full-time information specialist than in a freshly minted engineer, whose main value to the company is technical competence.

Government and private efforts to provide services that scan and translate Japanese technical literature have been only modestly successful so far. In the Japanese Technical Literature Act of 1986, Congress directed the U.S. Department of Commerce to set up an office to provide such services. The office established to do the job is small, staffed by two people and funded at less than half a million dollars per year, reprogrammed from other department funds. Initially, the office arranged for translations, but the service was so expensive ($60 per page) that there was little demand for it. Services still provided by the office include a directory of translation and monitoring services, a listing of important Japanese documents available in English, and a yearly report on important Japanese advances in science and technology.

A more direct and focused effort to learn about Japanese accomplishments in high-technology fields is JTECH, managed by the National Science Foundation in collaboration with other Federal agencies and funded at $600,000 in fiscal year 1990. JTECH sends teams of leading scientists and engineers to Japan to evaluate R&D in areas such as computer-assisted design and manufacturing of semiconductors, complex composite materials, and supercomputing. Workshops at NSF discuss the teams' preliminary findings, and the panel reports are distributed by the National Technical Information Service. In 1989, JTECH published reports on the much-discussed topics of superconductivity applications and high-definition television.

Learning the Japanese Language

For the long run, broader knowledge of Japanese among Americans is the best assurance that scientists, engineers, and business managers will be able to keep up with technological advances in Japan. And the best way to learn Japanese is to start early. Japanese school children get 10 years of instruction in English, from the elementary grades through high school. (Though the instruction is weak in conversational skills, most Japanese professionals learn to read some English.) It is the rare American high school that offers Japanese courses, and instruction in the elementary grades is practically nonexistent.

R&D CONSORTIA

Traditionally, consortia have played a much greater role in technology development in other countries, such as Japan and Korea, than in the United States. Antitrust law and the prevailing free

[87] One young engineer, a former AEA Japan fellow who now works for Hewlett-Packard, told the OTA-MIT workshop that he reads Japanese technical articles on his own, but few of his colleagues see the need. The company does not use his Japanese beyond asking him to translate occasional messages. U.S. Congress, Office of Technology Assessment, Technology *Transfer to the United States from Japan,* op. cit., p. 11.

[88] It might be thought that some of the Japanese scientists and engineers who study in the United States would stay and work for U.S. firms (ss Korean and Taiwanese researchers have done in large numbers), thus providing a source of technically trained people able to read Japanese. However, most Japanese have been little inclined to stay in America and work for American companies, and some Korean and Taiwanese are returning to their home countries even after many years of working for U.S. firms.

market ethos combined to make cooperative research appear inefficient or even illegal.

When American technology led the world, means of improving not just the technology but the process for creating it had little place in the public policy agenda. Yet as America's competitive position has deteriorated, and a state of crisis has emerged, especially in certain high-technology sectors like semiconductors, some now argue that R&D consortia are a critical element in the return to international competitiveness. The argument contains the following points.

First, as manufacturing processes become more complex and the technology more sophisticated, the cost of R&D rises. In particular, the sheer size of the investment necessary to advance to new generations in microelectronics implies risks unacceptable to all but a few large firms. For example, developing X-ray lithography technology runs into hundreds of millions of dollars. Such investments are beyond the reach of smaller firms, and even IBM is balking at that on its own. Consortia can allow the maximum leveraging of resources, by giving a company access to substantial R&D returns for a relatively small outlay. Companies can also ensure that they are in a position to appropriate the results of the research in that field-reducing a different risk, that they will be frozen out of a key development.

Second, U.S. industry is known for short-term thinking-which is a particular handicap in developing new technology. Consortia can reorient the perspective of participants toward longer term investment.

Third, there are externalities. Single firms may not be able to capture benefits from research that would nonetheless benefit the community as a whole. If a number of firms join together to do the research, the risks are spread and diluted.

Fourth, research consortia often have an important training function, even when they do not reach the technological goals they originally aimed for.

Fifth, consortia may improve the diffusion of new technologies by increasing the speed or the breadth of diffusion or both, a very important attribute. This may be especially true for consortia designed to help companies to catch up in areas of technical weakness.

Sixth, the creation of significant alliances and even a consensus among participants in the face of foreign competition can be useful. In textiles, for example, the Textile and Clothing Technology Corporation (TC^2) is credited with developing inter-and intra-industry linkages that have strengthened the domestic industry, even though the original technological goal of the project was not achieved.

All these benefits are important. If they were the only side of the story, strong backing for R&D consortia would bean obviously appropriate goal for public policy. But three main sets of drawbacks have been put forward. Some have stressed an anti-competitive and hence antitrust element of cooperative R&D; this argument becomes more telling for consortia that are further downstream toward manufacturing. Alternatively, some argue that R&D consortia have minimal effects-they simply don't work and are not a useful means of furthering competitiveness. Finally, there are questions about the relationship of the government to R&D consortia.

The problem of antitrust is discussed in the last section of this chapter and in chapter 2. However, since R&D consortia are under discussion here, the antitrust argument is not very relevant; few people see antitrust problems in nonproduction cooperation.

The second criticism is more cogent. Not all consortia are successful, but some are. The problem is to identify the circumstances that make for success, rather than offering simplistic generalizations. Some of the key questions are:

- *Goals. Are* consortia designed to attain some goals more successful than those aimed at others? For example, is basic research a more appropriate goal than research closer to commercial application? Does a consortium do better trying to produce new technology or should it simply focus on catching up with technology that exists elsewhere?
- *Players.* Who needs to be involved? Must the biggest firms in an industry be part of the consortium? Should all participants be roughly the same strength or size? Should the industry's technology leader participate? Do consortia with vertical participation fare better than those involving only firms from a single stage of the production process?

- *Financing. Are* there optimum forms of financing? Should the government help? How much?
- ***Technology transfer strategies.*** R&D consortia have two primary purposes-the creation of new technology, and the diffusion of technology. Can successful diffusion strategies be defined?
- ***Personnel.*** Firms are typically reluctant to send their best people to consortia. Does this matter, given that in some consortia most scientists are hired directly rather than being seconded from participants? How does this affect technology diffusion to participating companies?
- *Structure.* Does the structure of the consortium—timeframe, forms of participation, location of research labs, accrual of patent rights to insiders and outsiders, etc.-affect its success?

The third set of criticisms concerns the role of the government. In particular, the use of government money for R&D inevitably means that the government will have a say in which technologies to support. Critics argue that the U.S. Government in particular lacks the institutional capacity to make such choices.

This section examines some of the more important cases involving R&D consortia, focusing on the United States and Japan. It then offers some possible guidelines for cultivating successful consortia.

Collaborative R&D in U.S. High Technology: Electronics

The electronics industry accounts for the majority of joint R&D activity in the United States as well as in Europe and Japan. In the United States, most joint activity has occurred in the last 10 years. Early joint R&D efforts in this country were centered in universities, mainly because of antitrust concerns. Over time, and with relaxation of antitrust prohibitions, more joint efforts have been undertaken by private companies and those tend to be targeted further downstream.

This section looks at three different types of joint R&D in electronics: basic research (industry-university collaboration), long-term strategic research (MCC), and manufacturing R&D (Sematech). The following section looks at collaborative R&D more generally in Japan.

Basic Research: Industry-University Consortia

This form of research collaboration has grown rapidly in the microelectronics industry during the 1980s.[89] Usually, the projects focus on basic research and on training students in subjects that fit the industry's needs. Member firms are granted access to all research findings. They are also encouraged to send technical people to the university to do research for extended periods. They often use their university access for recruitment; this may be the most important aspect of cooperation for the firm. Universities benefit because the extra research funding helps them to attract and keep faculty and graduate students and to upgrade their laboratories and equipment. Also, it encourages interdisciplinary teaching and research-something that is hard to accomplish with the university's own resources.

Some programs are designed to promote regional development. An example is the North Carolina Microelectronics Center (NCMC), which draws on university faculty from the Research Triangle to conduct R&D in a center constructed and operated in part with State funds. Member firms work together in vertically integrated teams: NCMC's initial sponsors included a semiconductor manufacturer (General Electric), a telecommunications equipment maker (Northern Telecom), a semiconductor manufacturing equipment firm (GCA), and a supplier of manufacturing process gases (AIRCO). Although NCMC's success at economic development has been questioned, it appears to have been effective in achieving technical goals.[90]

In microelectronics, the Semiconductor Research Corp. (SRC) is a key case.[91] It plays the role " broker for the semiconductor industry's basic research activities. An early goal was to stem the proliferation of expensive and duplicative university facilities for R&D on integrated circuits, and in this SRC had some success. Through the SRC's technical advisory boards, member firms have also approached some consensus on the main technologies to push for rapid advance. In addition to shaping the research agenda in microelectronics, this team-

[89] Much of the material in this section is based on David C. Mowery, ' 'Collaborative Research: An Assessment of Its Potential Role in the Development of High Temperature Superconductivity, " contract report prepared for OTA, January 1988.

[90] Dan Dimancescu and James Botkin, *The* New *Alliance: America's **R&D** Consortia* (Cambridge, MA: Ballinger, 1986), pp. 9-10; 75.

[91] In 1989, SRC had 28 member companies and a budget of about $30 million, $20.4 million of that from industry.

building exercise helped lay the groundwork for Sematech.

SRC has had less success in transferring results of the research it funds to member firms. The reasons are not altogether clear, but a likely one is the typical difficulty companies find in making immediate use of basic research. Another is the separation between R&D and manufacturing in many member companies, and a third is the lack of a reward system within companies for adopting ideas developed outside.

Long-Range Strategic Research: MCC

The Microelectronics and Computer Technology Corp. (MCC) was founded in 1982 by leaders of the computer industry, galvanized by the threat of Japan's Fifth Generation computer project.[92] The idea was to share resources and risks, and to undertake mid to longer term R&D where individual companies might not venture. More than at its founding, MCC today conducts numerous specialized projects tailored to the needs of its members, and it is putting more effort into meeting the needs of smaller companies and into technology transfer. However, it has so far kept the ability to do some core, longer range R&D projects.

MCC funding is almost entirely private. It was the first U.S. industry consortium in a non-regulated industry, and is a large one, with a staff of 430 and an annual budget of around $65 million. It currently has 20 member firms (shareholders), drawn largely from the computer, semiconductor, and aerospace industries.[93] MCC's five research programs are application-driven; they are in advanced computing technology, computer-aided design, packaging and interconnect, software technology, and high-temperature superconductivity. They operate on 6-to 10-year horizons, with an increasing emphasis on spinning off interim products.

MCC originally expected to draw staff from its shareholders but the firms were reluctant for competitive reasons to assign their best people. Admiral Bobby Ray Inman, the first CEO of MCC, initially rejected 95 percent of the researchers sent by the member companies, instead hiring highly respected outside scientists who were attracted by the large R&D budgets, high wages, and the central mission of long-term R&D.[94] These direct hires now comprise 85 percent of MCC's staff.

The structure of MCC is also an accommodation to competitive rivalries. Each of the five main research programs is operated independently, and there have been strict rules (recently somewhat loosened) about information exchanges among scientists across programs. Shareholders can pick from among the programs, joining as few as one. This cafeteria structure allows member firms to work in areas where they are weak and keep their strengths to themselves.

Both MCC's structure and the large percentage of directly-hired staff have impeded the transfer of technology, particularly within the consortium. Inman noted that although these factors made managing MCC much more difficult, they also helped MCC to attract and maintain a sufficient number of shareholders.

The ***Six-Year Mark—As*** MCC ended its sixth year, evaluations were mixed. Membership was holding steady, and MCC managers believed that existing shareholders represent a generally solid core of supporters. But shareholders continue to withhold their best people and their best ideas from MCC: virtually every good research idea pursued by MCC has come from within the consortium. Moreover, member firms are demanding a more immediate bang for their buck, and some have said they are looking to lower their contribution to MCC. (Most of the shareholders pay at least $1.5 million per year; some 20 associate members pay annual dues of $25,000 for limited access to MCC research.)

For members, a basic problem is the dearth of clearly usable research results. Only three commercial products have resulted from MCC technology.[95] However, some firms also use MCC technology less directly, as Honeywell did to develop an internal product designed to place components on a multilay-

[92] The industry giants, IBM and AT&T, did not join, possibly for antitrust reasons.

[93] Member account for one-half to two-thirds of all firms in those industries, and most have R&D budgets of $100 million or more. Merton J. Peck, "Joint R&D: The Case of Microelectronics and Computer Technology Corporation," *Research Policy, 15, 1986,* pp. 224-225.

[94] Interview with Inman, Nov. 1, 1989.

[95] NCR Corp. recently introduced Design Advisor, an expert system for integrated circuit designers based on MCC's work in artificial intelligence. The consortium has also licensed its laser bonding technology, a technique for connecting the leads of semiconductor chips to the circuit board. Most recently, the Digital Equipment Corp. (DEC) announced plans to use MCC's tape-automated bonding technology in one of its VAX computer systems.

ered printed circuit board. Boeing has set up four labs in Seattle to develop technologies that it takes from MCC.[96] Other benefits are apparent but hard to measure. For example, access to MCC has allowed member firms to delay capital investments and then make the right ones when the time comes. And even negative results help shareholders to avoid blind alleys.

Nevertheless, MCC members and executives alike feel that the consortium should be spinning off immediately usable technology even as it pursues long-term projects. This pressure for results has been intensified by a change in the corporate level of interaction with the consortium; MCC executives refer to this as the ''kings, dukes, and barons progression. In place of CEOs with long-range visions (the founding members, or kings), responsibility for interacting with MCC has migrated downward to the managers of profit-and-loss centers (dukes and barons) in many member firms. These managers have much more immediate needs, and generally press for nearer-term payoffs.

A few shareholders--Digital Equipment Corp., Control Data Corp., and Boeing, for example-have made major technology transfer efforts. DEC spends half again its investment in MCC seeking ways to use the consortium's results.[97] But others largely ignore MCC. Scientists at MCC describe some shareholders as "black holes' because of the difficulty of locating-and then maintaining contact with-the appropriate recipient for a particular technology. "Too many [shareholders] are waiting around for a virtual product design to emerge before they examine what's happening and why they might use it, " Inman observed after he left MCC.[98] In addition to diverting MCC resources away from long-term research, this demand for neatly packaged results creates tensions, according to one program manager, because 'the weak sisters want us to bring the technology damn near to market," while the strong ones don't.

Some technology transfer problems arise in strong firms as well as weak ones. For example, MCC's CAD program serves a group of semiconductor manufacturers who have become increasingly dependent on the emerging software vendor industry. When MCC gave CAD members research algorithms instead of completed software tools, it was "like feeding grass to tigers," according to MCC's chief scientist, John Pinkston.[99] The CAD program director stepped down and the program was substantially reorganized. A similar problem occurred with MCC's much-praised laser-bonder. Most MCC shareholders could not use the technology in 'raw' form. It was eventually licensed to a non-member firm with the sophisticated capacity to make use of it.

Mid-Course Corrections-MCC has changed its structure to combine shorter with longer term projects.[100] The CAD program and two others were each reorganized into a core unit working toward long-range goals, plus several satellite projects, designed to produce ongoing results for shareholders. In these programs, shareholders must buy into the core project and at least one satellite. However, MCC's Advanced Computing Technology (ACT) program (by far the largest) recently eliminated the core structure altogether. A shareholder can now select from 12 medium-term projects—including neural networks, optical computing, and artificial intelligence—at an annual price of $125,000-$700,000 apiece plus a one-time fee of $250,000 for access to the program. Although some of ACT's $1.5 million contributors are sure to trim their investment, MCC hopes that new participants will more than offset that loss.

MCC has begun to seek government money in cases where shareholders fail to exploit its research or where the government funds complementary research. For instance, the shareholders did not pick up the parallel processing work of the advanced computing program, so MCC instead attracted a $6 million DARPA contract. Toward the end of 1989, MCC estimated that government contracts would

[96] *Management Review,* February 1989, p. 26.

[97] Among other things, DEC requires that every MCC project it supports have an individual sponsor within the company. By including the funding for external R&D in the budget for internal research projects, DEC encourages managers to pay close attention to the work of consortiums. *Scientific American, May 1989,* p. 100. DEC also works hard to put researchers returning from a tour with MCC into positions where they can help the company the most.

[98] Fred Guterl, ''MCC: The Dilemma of Joint Research," Business *Month,* March 1987, p. 50.

[99] Interview with Pinkston, MCC, May 12, 1989.

[100] For a discussion of MCC's reorganization, see J. Robert Lineback, ''MCC, After Five Years of R&D, Refocuses To Earn Its Keep,'' *Electronics,* December 1988.

grow from 2 or 3 percent of its budget to 10 to 15 percent in 1990. MCC now also does proprietary work for individual member firms. The packaging and interconnect program (MCC's most successful) runs such projects for five of its seven shareholders. These projects exploit other ongoing research and currently total less than 20 percent of the program's effort.

MCC is putting more resources into transferring its results. In 1988, for example, there were some 80 technology transfers to shareholders compared to a handful in 1985. Fully a quarter of MCC's budget now goes into technology transfer activities. Other, more qualitative changes include relaxing the barriers between programs, formal voting on program research to increase shareholder commitment to MCC's work, and attempting to increase the shareholder portion of MCC's staff to 35 percent. On the members' side, most do keep some people on the premises in Austin-and not just to see what other shareholders are up to, as in the early days, but to do real work. Although staff seconded from shareholders are still a small minority, those who are assigned there could be used to transfer technology back to the company.

MCC's ***Future—The*** shift in MCC toward more client-centered and more immediate results is in part a response to the needs of weaker members. One function of MCC is to help C companies become B companies, or help A and B companies strengthen weak areas. Thus the trend toward shorter term, more specialized R&D has positive aspects. At the same time, the trend could upset the balance between MCC's original goal, to take on long-term and relatively risky research, and the need to generate products that are more immediately or more narrowly useful to members of the consortium. It is this balance that distinguishes MCC from institutions that are devoted mostly to serving individual customers with proprietary R&D.

Manufacturing R&D: Sematech

SRC and MCC notwithstanding, microelectronics industry observers were skeptical about the 1987 announcement of a proposed manufacturing research consortium to be funded equally by industry and government. Twenty years of intra-industry competition would not be easily set aside. The newfound cooperation was partly based on fear, as Japanese inroads into the market for dynamic random access memory (DRAM) chips—the workhorse of the chip business—threatened U.S. firms' very existence.

Despite the similarities between MCC and Sematech, including a handful of common members, there are major differences. The Federal Government, consciously excluded from MCC, is a full partner in the 5-year chip consortium: DARPA is contributing $100 million per year, roughly half of Sematech's budget.[101] More important, Sematech's focus is narrower and more applied; it goal is to develop 0.35 micron manufacturing technology by 1993. Sematech's membership is relatively homogeneous: 14 semiconductor manufacturers, both merchant and captive, which together represent 80 percent of U.S. chip production capacity. Sematech's 15th member is Semi/Sematech, an organization of U.S. equipment and materials producers.

Sematech's members include IBM and AT&T, the industry giants that have stayed away from MCC. Sanford Kane, then IBM's vice president for industry operations, explained his company's rationale for supporting Sematech:

> The survival of the U.S. semiconductor industry was critical to us for several reasons. Number one, we were one of the largest purchasers of chips in the world. We liked to source locally, and we didn't want to be in a position where we had no choice but to be dependent on our competitor. Second, IBM was the largest manufacturer of chips in the world. We produced in-house those chips that gave us a technological edge. In order to stay state-of-the-m% we needed to have sophisticated equipment to make the semiconductors. If the U.S. chip makers go, so would the U.S. equipment companies. We knew it would be difficult to establish close relationships with the Japanese, especially since most of their firms are associated with chip companies. We would be forced to share information and it would be doubtful whether we could get access to state-of-the-art equipment as quickly as our Japanese counterparts.[102]

[101] DoD's support is scheduled to end in 1993. Robert Noyce anticipates that, if Sematech is successful, industry will continue to fund the effort without government support, albeit on a smaller scale. If industry is unwilling to fully fund Sematech after 1993, he maintains, it should be ended. "I'm a firm believer in sunset provisions,' says Noyce. Interview with Noyce, May 11, 1989.

[102] "Sematech," Harvard Business School Case #N9-389-057, 1988, p. 10.

So important is Sematech's success to IBM and AT&T that the two firms shared their respective 4 megabit (M) DRAM and advanced 64 kilobit (K) SRAM processing technologies to the consortium, along with the engineering support necessary to get them into operation. These contributions have allowed Sematech to establish baseline manufacturing with 0.7 and 0.8 micron technology less than a year after moving to its Austin facility. Although Sematech's fabrication facility (fab) will turn out only a few hundred wafers a day, just a fraction of a commercial fab's output, the consortium considers that sufficient to achieve rapid process learning. Sematech's strategic plan calls for high-yield, pilot application of 0.35 micron processing technology an estimated 6 to 18 months ahead of leading foreign chipmakers.[103]

Three strategic objectives are central to achieving this goal: 1) improving suppliers' technologies, 2) improving chip makers' manufacturing skills and techniques, and 3) strengthening the manufacturing technology base for semiconductor production.

Objectives-First of all, Sematech must strengthen U.S. materials and equipment suppliers. The industry includes hundreds of small supplier fins, most with sales of less than $10 million per year. These firms have traditionally had an arm's-length, and often adversarial, relationship with semiconductor producers, who preferred to keep their chip designs and manufacturing processes secret. A recent report describes the industry's situation:

> Compared with captive equipment makers in integrated Japanese and European electronics firms, U.S. equipment makers lack the advantages of predictable internal markets, access to broad scientific expertise, and deep pockets for high-cost R&D. They also lack the opportunity for joint development and internal site testing of new equipment, and the benefit of systematic high-quality feed-back on product performance.[104]

Sematech represents an attempt to overcome some of these structural handicaps. Through competitive R&D contracts to selected suppliers, it will try to promote long-term alliances between chipmakers and suppliers. Although chip producers are the source of two-thirds of the innovations in semiconductor equipment, they have traditionally kept these innovations secret, so as to preserve their competitive advantage in process technology.[105] The consortium structure encourages chipmakers to reveal their secrets to equipment producers.

By awarding contracts to multi-company teams, the consortium is also trying to promote cooperation and consolidation among suppliers. For example, a team composed of three rivals in high purity gas technology was recently awarded a contract to develop gas pipelines, filters, and other technology for Sematech.

The R&D funds awarded to selected suppliers will also be important, although probably less so than the knowledge it generates and improved relationships with chipmakers. Sam Harrell, president of Semi/Sematech, expects over half of Sematech's budget to filter down to equipment and materials firms in the first few years of the consortium.[106]

Finally, Sematech will provide a high-quality beta test site, where suppliers can test run their new equipment and processes under realistic manufacturing conditions. Currently, a supplier firm must test its equipment on an actual production line; since it can take weeks to debug a new piece of equipment, chipmakers are understandably reluctant to act as guinea pig. This test facility will also serve to certify the quality and composition of chemicals and other inputs.

Sematech's second objective is to improve manufacturing skills and techniques among chipmakers themselves and, in so doing, to change the very culture of semiconductor manufacturing in the United States. Sematech's director of strategic planning, A. S. Oberai of IBM, describes the problem this way:

> In Japan, engineers spend 70 to 80 percent of their time on "continuous improvement programs. " The process operator is king-the first line of attack. It is he who keeps the equipment in order and decides when to call in the engineers. In the United States, engineers spend 70 to 80 percent of their time on crisis management as opposed to crisis avoidance.

[103] The consortiums interim goal is to apply 0.5 micron manufacturing technology by 1990, roughly even with leading foreign chipmakers.

[104] "Sematech: Progresses and Prospects," Report of the Advisory Council on Federal Participation in Sematech, 1989.

[105] Eric von Hip@, The *Sources of Innovation* (New York, NY: Oxford University Press 1988).

[106] "Sematech," Harvard Business School, op. cit., p. 12.

> The system encourages that by rewarding doers—problem solvers—rather than problem avoiders. [In contrast to Japan, in the United States] process operators do no maintenance or planning-they just push wafers.[107]

Sematech should also provide an arena for the cooperative development of standard equipment interfaces-a key problem up to now—and members will be able to use their substantial market power to get those standards accepted industry wide. The ultimate goal is a computer-integrated manufacturing system, which will provide diagnostic information about chip manufacturing to a computer in a standardized format.

Sematech's third objective is to strengthen the manufacturing technology base. Through expert workshops, the consortium tries to identify the most promising paths to its various technical goals. In addition, 10 percent of Sematech's budget is going to 11 university centers of excellence,[108] whose activities are being directed by the SRC. The centers are conducting research in a limited number of areas that will be critical to Sematech's post-1990 activities: for example, contamination/defect assessment and control, and advanced plasma etch processing technology.

Preliminary Assessment—Sematech got off to a rocky start. Member firms clashed over the kinds and volumes of chips to produce.[109] There were problems in recruiting a CEO, and DARPA rejected the consortium's first operating plan. However, after a year-and-a-half of operation, Sematech has made significant progress. It has built a world-class clean room and fab in less than half the normal time and at lower cost. In March 1989, several days ahead of schedule, the consortium produced its first chips, using AT&T's SRAM technology.

Member company assignees to Sematech are generally high caliber, and the consortium has, unlike MCC, achieved its goal of balance between assignees and direct hires.[110] There is other evidence of members' commitment. National Semiconductor has built a pilot production line to apply the tools that Sematech is developing.[111] And some supplier firms appear to have made preliminary plans to locate R&D and production facilities in Austin.[112]

According to Sematech officials, members' commitment went 'from casual to urgent" following the Federal Government's decision to participate.[113] Whether or not DARPA's financial contribution is critical,[114] Federal participation is certainly important symbolically: it gave Sematech credibility and encouraged industry members to believe that government officials will take seriously their concerns about unfair Japanese trade practices.

The participation of IBM and AT&T is at least as important. Their contribution of leading-edge technology represents an enormous benefit to merchant firms-one that has probably outweighed any costs to them of Sematech membership. However, the real test of commitment will come only later, when merchant firms will receive much less relative to their contributions, financial and otherwise.

Even now, not everyone would agree that Sematech is a conditional success. One concern is with Sematech's decision to limit actual production of chips in its fab, in keeping with strong opposition from IBM and Texas Instrument to high-volume

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107 Interview with A. S. Oberai, May 10, 1989.

108 As of January 1990.

109 Some analysts argue that, in choosing high-volume Chips, Sematech is attacking the wrong problem. They see the industry's future in application-specific integrated circuits (ASICs), which are custom-made in small quantities.

110 According t. Larry Novak, a Texas Instruments assign= and Sematech's director of technology transfer, an assignment to Sematech is seen as "career enhancing. Slow growth of the industry has kept many employees from moving up the career ladder in their home companies. Sematech provides an alternative ascent route.

111 *New York Times*, July 2, 1989.

112 "Sematech: Progress and Prospects," Op. cit., p. ES-4.

113 Ibid.

114 Claude Barfield, American Enterprise Institute, in testimony before the Joint Economic Committee, June 8, 1989, argued that industry was prepared to fund Sematech on its own. However, Robert Noyce argues that semiconductor companies can ill afford the $100 million per year they contribute, since their profits are among the lowest in manufacturing.

production.[115] Some critics believe that a high-volume operation is essential for testing yield and reliability, and that frictions between design and manufacturing teams can otherwise be swept under the rug.

High-volume production would require attention to every step in the process chain instead of the current selective emphasis, principally on lithography. That would cost considerably more money than Sematech has available. Some believe that the consortium's budget is too small to ensure success. Financial constraints do force Sematech to place its bets on a limited number of technologies aimed at achieving 0.35 micron circuitry. If those bets prove wrong, as one member company liaison said, "Sematech will have bought the farm."

Even if Sematech's technology wagers pay off, as most experts expect, the consortium still faces major problems. Technology transfer is one: Will member companies actually adopt the manufacturing tools that Sematech develops, let alone the new 'culture' of semiconductor manufacturing? Similarly, will the new closer relations between chipmakers and their suppliers be sufficient or lasting? Finally, will all of Sematech's work translate into significantly greater U.S. market share?

Cooperative R&D Ventures in Japan

In a nation where corporations are famous for the ferocity of their competition, the continued use of cooperative research ventures could not have come about by accident. Several factors have combined to produce the level of joint research activity seen in Japan.[116]

First, the nation has a tradition of government efforts to promote cooperation between competing firms that dates back to the beginning of industrialization in Japan. This history has conditioned firms to accepting joint R&D.[117] Second, the stability of firms within industries fosters the development of a certain level of trust. Wakasugi describes membership in a research consortium as 'effectively perpetual."[118] Third, firms want to participate because they are afraid of letting rivals gain a competitive edge.[119] Companies do not invariably join R&D consortia when invited;[120] however, reluctance to flout powerful, respected government agencies such as MITI, combined with fear of missing the bus, usually win out.

On the government side, Japanese ministries are constantly engaged in turf battles. One way for them to gain size and prestige is to become the promoter of more and more cooperative R&D ventures. The Science and Technology Agency established the Japan Research and Development Corp. in 1961, the same year MITI started the Engineering Research Association program (ERA). When MITI announced a 10-year biotechnology research consortium in 1981, three other agencies responded with their own cooperative biotechnology projects. Government agencies provide substantial financial inducements for joint R&D, including loans whose repayment is contingent on the venture's success, rapid depreciation of equipment, R&D tax credits, and outright grants.

Finally, Japan's legal climate is extremely favorable to cooperative ventures. One of the clearest expressions of Japan's attitude towards antitrust is embodied in the regulation that, even if the Japan FTC feels they have a legitimate case, they cannot act if it would "cause a loss of international competitiveness" for that firm.[121]

Private cooperative research ventures are common in Japan, but they usually do not involve government participation. Although fully one-third of industrial R&D is collaborative, 90 percent of that

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[115] During the planning stages of Sematech, many industry officials argued that a high-volume production operation was essential foresting yield and reliability, but Texas Instruments did not want competition in the DRAM market. IBM also opposed high-volume production for a variety of reasons. Sematech members eventually agreed on a facility capable of high-volume production but with an actual output of only 200 wafers a day. *New York Times,* Mar. *5, 1987.*

[116] This section draws primarily on the following sources: Mark Eaton, ''MIT1 and the Entrepreneurial State: The Future of Japanese Industrial Policy,' unpublished monograph, 1987; George R. Heaton, Jr., ''The Truth About Japan's Cooperative R&D,' *Issues in Science and Technology,* fall *1988;* Jonah D. Levy and Richard J. Samuels, "Institutions and Innovation: Research Collaboration as Technology Strategy in Japan," MIT Japan Science and Technology Program, WP 89-02, April 1989; Daniel I. Okirnoto, "Regime Characteristics of Japanese industrial Policy," *Japan's High Technology Industries,* Hugh Patrick (cd.) (Seattle, WA: University of Washington Press, 1986); Richard J. Samuels, ' 'Research Collaboration in Japan," MIT Japan Science and Technology Program, WP 87-02, 1987; and Ryuhei Wakasugi, "A Consideration of Innovative Organization: Joint R&D of Japanese Firms," Shinshu University, Faculty of Economics, Staff Paper Series 88-05, March 1988.

[117] Levy and Samuels, op. cit. p.%'

[118] Rhuhei Wakasugi, 1987, cited in Levy and Samuels, op. cit., p. 38.

[119] Kozo Yamamura, ' 'Joint Research and Antitrust: Japanese vs. American Strategies,'' *Japan's High Technology Industries: Lessons and Limitations of Industrial Policy,* Hugh Patrick (cd.) (Seattle, WA: University of Washington Press, 1986), p. 187.

[120] Samuels (op. cit., p. 39) offers several examples of leading firms who shunned joint research when they believed they were far ahead of their rivals.

[121] Yamamura in Patrick, 1986, p.196.

is simply two-firm contracts between users and suppliers (i.e., firms that would not compete anyway). Only one-fifth of all joint research----or about 6 percent of total industry R&D-occurs between rival firms. These are the cases in which government participation is most common; because of competitive pressures, such alliances tend to succeed only with government sponsorship.

The typical vehicle for a joint project involving rival firms is the Engineering Research Association (ERA). The ***kenkyu kumiai ho*** (Cooperative Research Act), passed in 1961, gave ERAs the same legal standing as industry associations. Early ERAs were designed to help small and medium-sized firms catch up technologically, and so aimed to import and distribute technology, rather than develop it from scratch. In the early 1970s, ERAs entered a new phase. Although technological catch-up was still the goal, large firms began to play a bigger role and the focus shifted to more advanced research and product technologies. Critical to this change was a new MITI policy encouraged use of ERAs for "large-scale projects" involving research too extensive for any single firm to undertake. The projects (31 to date) were initially designed to meet specific goals, including creation of a prototype in some cases. The risk was primarily financial, since the technologies themselves had almost all been proven in the United States or Europe. A celebrated example of this kind was MITI's VLSI project (1976-79), which helped Japan's electronics firms master the manufacture of large-scale digital integrated circuits.

Around 1980, cooperative R&D in Japan entered a third phase, as the Japanese Government began to shift from catch-up to state-of-the-art projects. The Fifth Generation Computer Project, a successor to VLSI, is a 10-year national project focused on artificial intelligence and other leading edge technologies designed to make computers far more accessible to untrained users. Large-scale projects have become increasingly risky: for example, optoelectronic elements had not been proven when the Optical Measurement and Control System Project began in 1979. Similarly, the Next Generation Industries Program has turned increasingly to uncertain technologies such as bioelectronic integrated circuits.

As cooperative R&D in Japan entered its third phase, new vehicles were set up to promote cooperative research, and existing institutions are evolving to meet the new challenges. MITI and the Ministry of Posts and Telecommunications established the Japan Key Technology Center (KTC) in 1985 to fund promising proposals from research consortia. Much like a venture capitalist, KTC buys equity shares in the new firm-up to 70 percent of total capitalization. The research group, not the government, retains all patent rights.

Like ERAs, KTC consortia will have initial terms of 7 to 10 years and budgets for term of around $100 million. Unlike most ERAs, KTC projects must break new ground in basic or applied research, and the work is more likely to be conducted in joint facilities.[122] So far, KTC has provided more than $250 million in capital to 61 research projects. Eaton sees the program as a watershed: "It is difficult to overstate the significance of the KTC . . . It signals a new willingness by the Japanese, led by the state, to risk resources for basic industrial research. ''123

For all its contributions, joint R&D has not been the primary means of technical advance for Japanese industry. It has always complemented rather than dominated the research that companies were simultaneously doing in their own labs. Nevertheless, cooperative R&D ventures have proved technologically significant, especially in electronics. During Japan's period of catch-up, they provided an efficient way to rapidly raise the overall technological base of Japanese industry. As research consortia shift their activities to more exploratory research, success will be less predictable and more elusive, since uncertainty is the price of doing things that are really new. However, consortia do have the virtue of spreading the risks in uncertain ventures.

R&D consortia have also helped to speed the diffusion of technology between Japanese companies. Getting firms to share technology can be difficult. Though intellectual property laws are weaker in Japan than in the United States, they do provide some protection. The problem of technology sharing can be avoided if all the major player participated in its development in the first place. That way key capabilities are less likely to become proprietary, and the overall level of technological

[122] Eaton, op. cit.

[123] Ibid.

competence rises faster. No major firms are left behind in the technology race, and more firms mean more competition. (For further discussion of competition and technology diffusion, see the section *Intellectual Property.)*

As for the Japanese government's part in R&D consortia, the idea that Japan's technology advance is driven by a massive, government-directed program--a view fairly widely held in the West at one time-is untrue and largely discredited. It is a mistake, however, to underestimate the government's influence. Although government's annual spending per project is typically rather modest (the $300 million MITI spent over 4 years for VLSI was unusually high), the government commitment is steady and long-term, and this counts for a great deal.

Moreover, the fact that the government enters into relatively few R&D consortia should not be taken as a sign that the government's role is insignificant. The projects in which government participates are carefully chosen. Usually they are the upshot of continuing discussions between government agencies and business councils. They are consistent with the "vision," also developed by government and industry, of what kinds of technologies and industries are essential to the Japanese nation. Projects in the 1970s and 1980s were chosen for their contribution to the Japan's becoming a knowledge-intensive society.

Thus, the government's choices are both strategic and symbolic. They also give a signal. Private banks and financial institutions follow MITI's lead. And funding of joint R&D is only one of a whole raft of tools at the government's disposal for supporting strategic technologies. Besides the special loans, grants and tax breaks companies can get as inducements for joining R&D consortia, they may also get similar benefits from government programs in the commercial development that follows.

Making Successful Consortia

The innumerable factors (ranging down to the personalities of key participants) that affect the outcome of R&D consortia prevent the development of a recipe. Nonetheless, it is possible to offer some guidelines.

Because companies in the same industry are primarily competitors, minimizing conflict between consortium participants is critical. It is always difficult to get participants-often with long histories of competitive relations-to work together on anything, although successful cooperative research demands that they do. Consortia which fail to reduce conflicts to workable levels either collapse during the planning stages or find their effectiveness sharply reduced.

Conflicts can be avoided in more than one way. First, the evidence from Japan suggests that cooperation is more easily established when a technology is already known. Catch-up consortia have the advantage of avoiding certain conflicts by definition; for example, the participants need have little fear that any monopoly-creating technological breakthrough is at stake. Catch-up consortia also benefit from their clear goals, which make them inherently more likely to succeed than new technology consortia. This comparison by itself is misleading, however. Catch-up consortia should be compared with other catch-up mechanisms, not with new technology consortia. Likewise, new technology consortia should be compared with other mechanisms of technological innovation.

It may also be easier to avoid conflicts when a cooperative project is aimed at goals far from the competitive arena. For this reason, some claim that R&D consortia should be aimed at basic industrial research rather than applied research. Yet if participants can agree on well-defined areas of precompetitive research, they can overcome the potential for conflict. Indeed, international competitive pressures can be so strong in some cases that participants become exceptionally interested in making major cooperative R&D efforts that go right through pilot production (e.g., Sematech) perhaps even into commercial manufacturing (e.g., Airbus). Moreover, the results of applied research may be more useful to consortium members than yet another increment of basic research-in which the United States is already strong.

Conflict is not the only impediment to success. Ultimately, success comes only when the products of a consortium are adapted and integrated into the mainstream of participating fins' operations. There are several ways of encouraging diffusion of the results from cooperative R&D. Most important, a substantial financing commitment from participants seems to be necessary. Firms pay attention when enough of their own money is at stake. Of course, defining "enough" is possible only case by case;

Sematech defined it as 1 percent of each fro's revenues. Another funding strategy is to make sure that the resources given to the consortium are taken from the budget of the department in the firm that is responsible for using the consortium's results.

Another issue is personnel. Firms do not often send their very best people to R&D consortia. But if they send fourth-best personnel, the consortium will have no credibility within member fins. Firms must recognize the problem and send at least their second-best people, if the consortium's results are to get an attentive hearing. Also, a powerful patron for the consortium within the member firm helps to ensure that the results are exploited; without such a patron, the consortium can easily fall victim to the ''ilot-invented here' syndrome.

To establish closer links between consortia and at least some participants, the EC (almost always) and the Japanese (sometimes) have located their consortia research within the labs of participating firms. In contrast, MCC and Sematech have their own labs. Another diffusion strategy is the promotion of parallel research. Japanese firms taking part in consortia often have entire research labs devoted to shadowing the consortiums results.

On a slightly different point, one key reason why Japanese companies take part in consortia is to keep an eye on what their competitors, domestic and foreign, are up to. Technology diffusion is an acknowledged weakness of U.S. manufacturing (see ch. 6). If R&D consortia succeed not only in transferring their own results effectively to members, but also in raising members' awareness more broadly of technology advances in their field but outside their members' own area of emphasis, then the consortia will have served a useful purpose.

The Role of Government

Government should try to ensure that consortia it supports are designed appropriately, taking to heart the lessons described above. But this is not sufficient grounds on which the government can make a choice of projects. For example, it is necessary but not at all sufficient that the project have enthusiastic participation (including a hefty financial commitment) from industry. The government—with its inevitably limited funding-must also have some notion of the extent to which the projects it supports are important for the economy as a whole.

Some areas of technological advance offer long-term benefit to society but do not attract sufficient private investment because they are high-risk activities with uncertain pay-offs, and are very expensive. In the past, industries and technologies have been supported by the government on the grounds that they were vital for the nation's security. But today other grounds appear more pressing. Certain industries have vitally important spill-over effects: knowledge-intensive industries have ramifications far beyond their own (fast-expanding) boundaries; the whole complex of industries that the Europeans call ''telematics' directly affects the competitiveness of many other industrial sectors. And there are other "key" technologies. It is not an accident that both Japan and the Europeans have targeted the same key industries and technologies.

The notion that some consortia are more worthy of government support than others implies that some government agency must make that determination (see ch. 2). It is fair to argue that any large-scale shift toward cooperative R&D with government support will, in the end, imply the kind of choices that a civilian technology agency would be designed to make. Only such an agency could have the necessary expertise.

This brings up a final important point. While the government must seek to ensure that its support goes to projects that are both valuable and likely to succeed, government support is itself a factor in the equation. In Japan and Europe, government support provides both cash and credibility to a project, and may make the difference between success and failure. That, after all, is why these governments' support for R&D projects can be justified: if government money did not make the difference between success and failure, there would be no need for that spending in the first place.

INTELLECTUAL PROPERTY

Intellectual property rights, once largely ignored in our Nation's trade policy, are now an important issue. Foreign firms skilled at imitation are said to be stealing our inventions, and weak protection of intellectual property is held to blame. The United States is negotiating for stronger rights worldwide (including better enforcement), both bilaterally and in multilateral negotiations of the General Agreement on Tariffs and Trade (GATT) and the World Intellectual Property Organization (WIPO). There is

also concern to maintain strong protection in this country-especially against infringing imports.

Attention has been focused on the whole range of intellectual property rights, including (among other things) patents for inventions; copyright for books, records, and computer software; and laws concerning trademarks used to identify a fro's goods.[124] This section, however, addresses only those intellectual property rights that directly protect technological innovation, including patents and software copyrights. Generally, the term "intellectual property" in this section denotes only intellectual property of this sort. (Box 7-D describes those intellectual property rights and explains how their effectiveness can vary.)

Inventors do not always need legal protection to keep imitators out of the market. Sometimes they can keep the new technology secret long enough to get a good lead in the market.[125] For example, it is hard for an outsider to determine the exact composition of many chemicals, and still harder to determine the process used to make them. In other cases, secrecy is not feasible. Many products are rather easily examined and duplicated—machinery, for example. Even computer chips, with their microscopic maze of interconnecting circuits, are surprisingly easy to copy. Information can also leak out through employees switching firms, and through suppliers and customers. In many industries, detailed information about new products and processes often leaks out to competitors within a year after they are developed.[126] When secrecy breaks down, inventors may turn to the legal protection of intellectual property rights.

The U.S. interest in intellectual property rights to protect technological innovation is not surprising. While other countries have surpassed us in implementing some new technologies, the United States is still a world leader—perhaps *the* leader—in discovering new technologies. The inventor of something new has an obvious interest in keeping to himself the right to make and sell the thing-or in extracting royalties if he wishes to sell that right to others.

The case that stronger protection would yield great dividends is not clear, however. Protection of inventions is only one factor—by no means the most important-in competitiveness. Furthermore, the net effect of stronger protection on the advance of technology is uncertain. While it might encourage R&D by rewarding inventors, it can limit the diffusion of the new technology. Finally, it is not easy to persuade less developed countries, where intellectual property protection is relatively weak, to raise their level of protection. While intellectual property protection does matter, even the best foreseeable changes in protection here and abroad will probably have at best a modest positive effect on U.S. manufacturing. The most promising avenues of change are: 1) streamlining enforcement of patent rights in the United States and Japan, and 2) harmonizing patent procedures among different countries.

How Much Can Increased Protection Help?

This section considers whether: 1) stronger protection for technological innovation can prevent large trade losses to imitators, 2) stronger protection would make the U.S. economy (and other economies) more efficient by encouraging research and development, and 3) the United States can convince other countries to increase protection.

Preventing Losses

It is not known how much the U.S. trade deficit is increased by gaps in intellectual property protection. The U.S. International Trade Commission (ITC) estimated that for 1986 these gaps caused U.S. firms to lose revenues of $43 to $61 billion.[127] This figure is extrapolated from survey responses by selected firms with estimated losses totaling $23.8 billion. The sum includes at least $1.8 billion in sales lost directly in the United States to infringing imports, $6.1 billion in sales lost directly abroad because of

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[124] For a more general discussion of intellectual property rights, see U.S. Congress, Office of Technology Assessment, *Intellectual Property Rights in an Age of Electronics and Information*, OTA-CIT-302 (Springfield, VA: National Technical Information Service, 1986).

[125] Trade secrets law Cm protect against competitors' use of information gained by unauthorized access.

[126] Edwin Mansfield, ' 'Ho. Rapidly Does Technology Leak out?" *The Journal of Industrial Economics*, vol. 34, No. 2, December 1985, pp. 219-221. Mansfield reported on a survey of 100 firms in 13 industries, chosen at random from those industries' high R&D spenders. Ibid., p. 217, fn. 2.

[127] U.S. International Trade Commission, *Foreign Protection of Intellectual Property Rights and the Effect on U.S. Industry and Trade* (Washington, DC: USITC Publication 2065, February 1988), pp. H-2 through H-3.

Box 7-D-Intellectual Property Rights Protecting Innovation

Intellectual property rights follow national boundaries. They are granted by national (or state or provincial) governments, and apply only within the national territory. A firm that desires rights in other countries can seek such rights from those countries, If a firm's rights are being violated in a foreign country, it must go to that country's courts for monetary compensation or an order stopping future violations.

The most important intellectual property right for protecting technological innovation is the patent. Patents are granted by a national government for inventions of new, useful, and non-obvious products or processes (including new, useful, and non-obvious improvements of existing products and processes). A patent grants the right for a fixed period (in the United States, 17 years) to stop others from doing the following things *within the* national *territory:* making covered products; using or selling covered products, wherever they were made; using covered processes; and (in some cases) using or selling products made abroad by covered processes.

Other rights include copyright, semiconductor mask work protection, and trade secrets+ Copyright is the right for a fixed period (in the United States, the term varies depending on circumstances but is at least 50 years) to control the copying and other dissemination of textual, artistic, or other expressions; it is significant for protecting technology because in the United States and many other countries, copyright protects against the copying of computer programs and data. Mask work protection, a new form of protection created by the United States in 1984 and since adopted by other countries, protects against copying the layouts of semiconductor chips, which involve elaborate interconnections and are very expensive to design. Trade secrets law concerns the stealing of a firm's secrets, including technical know-how. Depending on the law, a firm which has tried to keep its knowledge secret may be able to stop other firms which gained unauthorized access to this knowledge from using it.

The scope and effectiveness of protection varies from country to country. For example, Argentina, India, Brazil, and Mexico do not grant patents for pharmaceutical products, and Brazil does not grant patents for processes for manufacturing pharmaceuticals. Also, the duration of patent protection varies. The United States generally grants protection for 17 years from the date of the patent grant, while in India patents concerning foods, pharmaceuticals, veterinary products, pesticides and agrochemicals last only 5 years from the patent grantor 7 years from the application, whichever is shorter. Some countries require that, when it is in the national interest, patent owners must grant a license to a local producer. If the parties cannot agree on a royalty rate, an administrative or judicial authority will set one.

Thus, the laws vary in scope; but the effectiveness of protection might depend still more on procedures for enforcing legally defined rights. For example, applying for and enforcing patents can be costly, especially in foreign counties where companies have to hire foreign patent lawyers and pay to have documents translated. Application and enforcement proceedings often take several years, during which time others are in most cases free to imitate the invention. Moreover, the rules of procedure and evidence in some countries might make it difficult to prove that a violation has occurred.

inadequate protection, and $3.1 billion in lost royalties.[128] It also includes other items, such as reduced profit margins, business never attempted abroad, loss of manufacturing economies of scale, and the effect of a weakened sales force on other product lines. The ITC's report did not quantify these other items separately.[129]

As the ITC acknowledges, projecting from the 193 companies that estimated lost revenues to the whole U.S. economy is problematic. Even for these 193 companies, the ITC depended on firms' own estimates of their losses. It is hard for a firm to state confidently how much it has lost even in direct sales, and even more so for other items such as hypothetical losses from sales never attempted. The estimates could also be too high if the firms incorrectly believed that certain goods were infringing. In addition, the ITC study concerned infringement of all intellectual property. If losses were restricted to technology-based intellectual property, the subject under investigation here, the ITC's estimate would probably be at least 10 percent lower.[130]

[128] Ibid., pp. 4-5, 4-6. These three figures are compiled from firms that estimated these items separately. Other responding firms may have incurred these losses but did not estimate them separately.

[129] Ibid., p. 4-4.

[130] Entertainment, food and beverages, publishing and printing, and textiles and apparel comprise $2.43 billion of the total losses of $23.8 billion. Ibid., p. 4-3. These particular categories probably involve almost exclusively trademarks and literary or artistic copyright.

More fundamentally, the existing forms of protection cannot always protect against imitation. Even when a firm has a patent, others can often invent around it—i.e., develop alternative technologies to get the same result.[131] The patent does give the original inventor a headstart while others catch up. During this time, the inventor might be able to improve the manufacturing process, expand production to exploit economies of scale, and develop marketing channels ahead of his competitors. If competitors are better at manufacturing or marketing, however, they can overtake the inventor. This has happened many times. A classic example is the CAT scanner, whose inventor was eventually rewarded with a Nobel prize. The invention was carried out for the British firm Electrical Musical Industries (EMI) Ltd. in the late 1960s. Although EMI produced and sold the CAT scanner successfully at first, the company lost its lead in the U.S. market half a dozen years after introducing it there; its biggest, most successful competitor was General Electric, which quickly developed a somewhat improved scanner and provided hospitals with superior training and servicing. A couple of years later, EMI dropped out of the CAT scanner business.[132]

Promoting Economic Growth

The theoretical basis for intellectual property protection is to promote economic growth by encouraging research and development—a factor of special importance to the United States, since U.S. manufacturing competitiveness depends heavily on technological superiority. Without strong protection, the argument goes, many innovations that would benefit society as a whole might never be made because the innovator could not make enough profit to recover the costs of research and development and compensate for the risks of failure.[133] It should be borne in mind that not all R&D pans out. Profits on the successes must be great enough to cover the costs of the inevitable failures as well. In addition, the world today is so full of competent manufacturers that imitation is occurring faster than ever, making it increasingly harder for innovators to recover enough profits. If they are to get sufficient reward for their inventions, they need strong protection of the law.

This argument for intellectual property protection has some force. However, there is evidence that many inventions would still be made even if legal protection were unavailable.[134] In an opinion survey, 100 firms in the United States were asked what percentage of their patentable inventions commercially introduced in 1981-83 would have been introduced even if patent protection were not available. The answers, by industry, were: 35 percent in pharmaceuticals, 70 percent in chemicals, 80 to 90 percent in petroleum, machinery, and fabricated metal products, and over 90 percent in primary metals, electrical equipment, instruments, office equipment, motor vehicles, rubber, and textiles.[135] In another opinion survey, 130 firms rated patents as fairly ineffective in many industries, including electronics; secrecy and lead time were generally considered more important.[136] Another study also found that patents provide relatively little protection

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131 Inventing around patents is relatively easy in electronics, and relatively difficult in pharmaceuticals. Richard Levin, Alvin Klevorick, Richard Nelson, and Sidney Winter, "Appropriating the Returns From Industrial Research and Development," *Brookings Papers on Economic* Activity, No. 3, 1987, p. 811; Edwin Mansfield, Mark Schwartz, and Samuel Wagner, "Imitation Costs and Patents: An Empirical Study," *Economic Journal,* vol. 91, 1981, p. 913. In general, broader interpretation of what a patent covers can make the patent harder to invent around.

132 David J. Teece, "Capturing Value From Technological Innovation: Integration, Strategic Partnering, and Licensing Decisions,' Technology *and Global Industry: Companies and Nations in the World Economy,* Bruce R. Guile & Harvey Brooks, (eds.) (Washington, DC: National Academy Press, 1987), pp. 65-66,85-86.

133 Most often the major expense is not in making an *invention* or *discovering* a new result, but rather in subsequent development work culminating in commercial production.

134 The literature on this point is reviewed in Wesley Cohen and Richard Levin, "Empirical Studies of Innovation and Market Structure,' *Handbook of Industrial* Organization, Richard Schmalensee and Robert Willig, (cd.) (New York, NY: North Holland, 1989), vol. 2, pp. 1091-1093.

135 Edwin Mansfield, "Patents and Innovation: An Empirical Study," *Management Science,* vol. 32, 1986, pp. 174-175. The firms were also asked what percentage of their patentable inventions made during 1981-83 would have been made even if patent protection were unavailable; the responses were similar, The firms were chosen at random from 12 U.S. industries (excluding very small firms). Of the 100 fins, 96 responded,

136 Richard Levin, Alvin Klevorick, Richard Nelson, and Sidney Winter, op. cit., pp. 790, 792, 794, 796-797,811. The firms also rated process patents less effective than product patents. The data suggests several reasons: processes are easier to keep secret and firms prefer to keep processes secret rather than disclose them in a published patent; processes are patentable less often than products; competitors can find alternative processes more easily than alternative products; competitors' uses of patented processes are harder to detect and prove than competitors' manufacture and sale of patented products. Ibid., pp. 794 (table 1), 797 (table 2), 803 (table 5).

in electronics, compared to drugs and chemicals.[137] Yet the electronics industry spends about 8 to 9 percent of sales on R&D, compared to an average of about 3 percent for all R&D-performing manufacturing industries.[138]

In addition, the social benefit of encouraging R&D must be balanced against certain social costs. One cost is reduced diffusion of new technology—including technology that would have been developed even without legal protection. By exercising intellectual property rights, an innovator can prevent others from using the new technology. Thus, people wanting to buy products dependent on the new technology might find the products expensive or unavailable because competition has been stifled. Perhaps even more important, other researchers will be reluctant to build on a protected invention (e.g., by improving it or by applying it in a new way), since the original inventor may try to stop other firms from using any derivative technology. (And if the inventor is willing to license the invention, the royalties might be more than most firms would pay.) For example, the semiconductor industry would have been slower to take off if AT&T had been able to keep others from using the key technology covered by its early transistor patents.[139]

While all patents to some extent risk inhibiting technology diffusion, some recent patents with a broad sweep have aroused particular concern. These include patents on software to display multiple windows on a computer screen and to compare the texts of different versions of a document,[140] and a patent on a new mathematical technique to solve problems such as routing of telephones and scheduling of airlines.[141] The courts might interpret such patents narrowly or find them invalid altogether—but first some firm must have sufficient stake in the issue to mount a court challenge. In some fields, the danger of inhibiting technology diffusion might be relatively low. For example, patents on existing pharmaceuticals generally do not stop rival firms from developing and marketing new pharmaceuticals based on different active ingredients (although patents would stop rival firms from developing, for example, new dosage forms of existing pharmaceuticals).

Patents can also help diffusion of technology, because they are published and must explain how to practice the patented technology. Upon reading a patent, an expert in the field might think of follow-up work or might think of a way to achieve the same result in a different way, outside the patent's purview. Many Japanese firms routinely track patent applications (which in Japan are published 18 months after filing) to learn about new technology. In the United States, applications are published when a patent is granted—typically about 2 years after the application is filed. However, this published information often could be learned instead by examining the products.

There are also costs of running the legal system. Patent applications can be expensive for inventors to file and for the government to evaluate. Lawsuits between patent owners and alleged imitators are expensive for the parties and take up valuable court time. Moreover, in many lawsuits the court finds that no patent rights have been violated, so the time and expense was for naught---a, worse, the suit might even have been brought deliberately to harass legitimate competitors and scare their customers. Another cost is that, to the extent the law is unclear or its enforcement unpredictable, business planning is hindered for both inventors and possible competitors.

Since intellectual property protection entails social costs as well as benefits, providing ever stronger intellectual property protection does not necessarily promote economic growth. The best results come from protection strong enough to encourage innovation but not so strong as to greatly inhibit technology diffusion—with some attention to making enforcement predictable and inexpensive. Unfortunately, determining what level of protection would work

137 Edwin Mansfield, Mark Schwartz, and Samuel Wagner, op. Cit., p. 913.

138 National Science Foundation, *National Patterns of R&D Resources: 1989*, Final Report NSF 89-308 (Washington, DC: U.S. Government Printing Office 1989), p. 65. This source gives ''Company R&D funds as a percent of net sales in R&D-performing manufacturing companies by industry' for 1986. The percentage for electronic components (SIC 367) is 8.5; for drugs and medicines (SIC 283), 8.8; for other chemicals (SIC 284-285, 287-291), 2.6; and for all industries combined, *3.2.*

139 U.S. Congress, Office of Technology Assessment, *International Competition in Services,* OTA-ITE-328 (Springfield, VA: National Technical Information Service, July 1987), p. 216. As part of a 1956 consent decree settling an antitrust suit against it, AT&T agreed to license its transistor patents to other firms.

140 Lawrence Fisher, ''Software Industry in Uproar Over Recent Rush of Patents,' *The New York Times,* May 12, 1989, p. D1.

141 Gina Kiolata, ''Mathematicians Are Troubled by Claims on Their Recipes, " *The New York Times,* Mar. 12, 1989, p. E26.

best is largely a matter of guesswork. Empirical studies of how the level of protection affects the total amount of innovative activity (both invention and diffusion) are few and inconclusive.[142] Other effects might also be weighed in the balance. For example, strong patent and trade secret protection can make it harder for employees in an established firm to leave to found their own firm in the same field of technology.[143] Whether this effect is desirable depends on the characteristics of particular industries.

Another effect is that strong protection at home can be a bargaining chip abroad. In the 1960s, both IBM and Texas Instruments gained permission to produce and sell in Japan only by agreeing to grant Japanese firms licenses under their key U.S. patents for computers and semiconductors respectively. In effect, IBM and Texas Instruments gained access to the Japanese market in exchange forgiving Japanese firms access to the U.S. market.[144]

Finally, in considering the optimum level of intellectual property protection, it should be borne in mind that intellectual property protection is not the only way to encourage innovation. For example, the government can fund research and development, give tax breaks or preferential financing to industry investing in R&D and in modern equipment, and collaborate in industrial R&D projects. On the whole, compared with some other countries, the United States has chosen to rely less on these other means of encouraging innovation and more on protection of intellectual property. This choice probably arises from the fundamental, widely held view in this country that government and civilian industry should be separate. Intellectual property protection is seen as proper: it simply lets firms make profits in the marketplace based on their inventions. The alternative that the United States has most strongly embraced—support for basic research and for defense R&D-involves little interaction between government and civilian industry.

If the United States were to put more emphasis on various other means of encouraging innovation, intellectual property protection might become less important.

Convincing Other Countries

Assuming that stronger worldwide protection of intellectual property could improve U.S. competitiveness, is there a realistic prospect that other countries can be persuaded to change their laws? Generally, the less economically developed a country is, the less it desires intellectual property protection.

Less developed countries are not much moved by the argument that imitation is a form of stealing because it takes the benefits of R&D without sharing the costs. These countries are apt to reply that they are already much poorer than we are, and that strong intellectual property protection would just aggravate the difference. Stronger protection would benefit innovators in rich countries while driving prices higher for consumers and stopping capable local imitators in poorer countries.

The argument that protection is good for economic development in the long run, because it encourages local innovators, also falls on stony ground. Imitation of existing technologies is at least as well proven as a springboard for economic development as local innovation. Korea and Taiwan are modern examples. The United States, as colonies and as a nation, based much of its own earlier economic growth largely on imitation of European technology.

Finally, developing countries are urged to consider that they may not always be able to imitate. Sometimes they will need to buy technology from foreign firms, and these firms might refuse to license or sell technologies in countries that lack adequate intellectual property protection. This possibility does not seem to scare developing countries much. For example, many complaints have been lodged about unlicensed imitation or "piracy" of inventions in Korea, yet Korean firms have found willing sellers of technology among U.S. innovators, especially in the semiconductor industry.

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[142] Wesley Cohen and Richard Levin, "Empirical Studies of Innovation and Market Structure," *Handbook of Industrial Organization*, Richard Schmalensee and Robert Willig, (cd.) (New York, NY: North-Holland, 1989), vol. 2, pp. 1089-90, 1094-95.

[143] When a parent firm sues a spinoff for alleged patent or trade secret violations, the cost of fighting the suit can intimidate the spinoff, regardless of the merits of the case. The parent's motivation is often more to prevent hiring away of employees than to protect intellectual property--as shown by the terms of settlements. Professor John Barton, Stanford Law School, personal communication, June 12, 1989 and Feb. 1, 1990,

[144] U.S. Congress, Office of Technology Assessment, *International Competitiveness in Electronics*, OTA-ISC-200 (Springfield, VA: National Technical Information Service, November 1983), pp. 193-194.

If the United States cannot persuade other countries that strong intellectual property protection is in their own interest, it can resort to carrots and sticks. The carrot is often exemption from tariffs for certain imports from that country under the Generalized System of Preferences.[145] The stick can be denial or withdrawal of such benefits, or flexible retaliation (often in the form of punitive tariffs on certain goods) under the recently strengthened Section 301 of the Trade Act of 1974. This approach has achieved some success. For example, partly because of sustained U.S. pressure, Singapore strengthened its copyright protection generally and also applied it to software.[146]

If other countries under our urging do pass tough-sounding laws, that does not guarantee their enforcement. Enforcement requires sophisticated governmental apparatus. A country that has trouble feeding its population cannot be expected to spend large amounts of money to ensure speed and fairness in processing patent applications and trying patent suits. Moreover, a country that has been pressured into granting intellectual property rights might be particularly inclined to give enforcement efforts a low priority.

Specific Problems

Efforts to strengthen intellectual property protection are likely to be most effective when aimed at protection in the United States and in other developed countries. Both have large markets for the products of U.S. technology; and developed countries have more interest in granting strong protection. The weak spots in these countries largely concern procedures for administering and enforcing the law, rather than the law's substance.

U.S. Patent System

Courts in the United States have ruled more favorably toward patent holders in the 1980s than in the 1960s. This applies to rulings on patent validity (in particular, whether an invention was sufficiently non-obvious to merit a patent); scope of coverage (how broad a range of possible imitation is prohibited by the patent grant); permissible conduct by the patent holder (e.g., whether the patent holder may impose various marketing restrictions on its licensees); and compensation to be awarded for infringement. The changed legal climate in part reflects a shift in viewpoint. Traditionally, judges enforced patents narrowly on the ground that patents created undesirable monopoly rights. Increasingly, however, judges have viewed patent rights as simply a legitimate incentive and reward for innovation. In addition, in 1982 patent-related appeals were consolidated in one court, the U.S. Court of Appeals for the Federal circuit. That court's rulings have strengthened and clarified patent law. In fact, some believe that this court has tilted the law too far in patent owners' favor.

The effectiveness of U.S. patent law is limited by delay in enforcement. It takes over 2 1/2 years, on average, to bring a patent case through trial for a ruling.[147] Only then (with fairly rare exceptions) can the patent owner get a court order to stop the imitation.[148] A firm whose patent is being infringed might not make it to the end of the trial, and even if it does the court might not fully compensate for the harm.

Delay is particularly troublesome in suits against imported goods. Often it is hard to trace these imports back to their source, to find out whom to sue. Moreover, the U.S. courts have no way of enforcing a ruling against a foreign manufacturer who has neither assets nor employees in the United States. If the manufacturer is beyond the court's power, the patent owner must sue domestic distributors instead. (The same is true for other intellectual property rights, including copyright, mask work, and trade secret.) The patent owner might hesitate to sue, for the foreign manufacturer's distributor might also be his own, for the same product or others. Even if the court rules for the patent owner and orders the distributor to stop selling the infringing goods, the

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145 While granting such preferences might be consonant with our overall foreign policy objectives, these preferences do make foreign competition stronger in the U.S. market, thus to some extent offsetting the gain in our total competitive position due to stronger intellectual property protection abroad.

146 R. Michael Gadbaw and Timothy Richards, *Intellectual Property Rights: Global Consensus, Global Conflict?* (Boulder, CO: Westview Press, 1988), pp. 313,329.

147 *Annual Report of the Director of the Administrative Office of the United States Courts 1988*, p. 221. This report shows a median time of 31 months from filing to disposition of patent cases after trial; the arithmetic mean, or average, would probably be somewhat greater, since 90 percent of the cases take at least 11 months and 10 percent of the cases take at least 62 months.

148 It is in principle possible to get such an order before trial, called a preliminary injunction. However, in practice it is very hard for a patent owner to get such an order unless he has already won a prior lawsuit based on that patent.

foreign manufacturer need only switch to another domestic distributor. The patent owner will then have to start all over again, first identifying and then suing the new distributor.

The owner of a patent or other intellectual property right can avoid these multiple lawsuits by filing a complaint with the U.S. International Trade Commission (an independent Federal agency) under Section 337 of the Tariff Act of 1930, as amended.[149] If the Commission finds that imports are violating the complaining party's intellectual property rights, it can issue an exclusion order, enforced by the Customs Service, barring importation of those goods. Moreover, the Commission is required to render a decision within a year (18 months in a minority of cases deemed "more complicated"), a considerably shorter time than the average a court suit takes.

The GATT has ruled that Section 337 violates GATT treaty provisions by providing special, harsher enforcement of the patent laws where foreign goods are concerned.[150] Section 337 is still in effect. However, other GAIT members could now retaliate against future use of Section 337 against their fins. The GATT decision found many aspects of Section 337 inconsistent with the GATT treaty, and it will be difficult to amend Section 337 to bring it into line with the GATT decision while still keeping the core advantages of: 1) a quick decision, and 2) an exclusion order.

Japan's Patent System

U.S. firms have often been frustrated by the ineffectiveness of Japan's patent system in protecting their inventions.[151] Part of the problem has stemmed from U.S. fins' lack of familiarity with how the system works. Difficulties have also occurred due to the language barrier. But part of the problem stems from the nature of the system, especially from delays and a public policy that favors granting of licenses to those who improve on a basic patent.

While precise figures are not available, it seems that an application for a Japanese patent, if opposed vigorously by another firm, will generally be tied up for at least 6 years before an inventor can proceed with a lawsuit. (Patent applications in the United States take an average of less than 2 years.) After a patent is issued in Japan, a firm accused in court of patent infringement could probably cause the lawsuit to take at least 3 to 4 years.[152] (U.S. patent trials are not much quicker. They average somewhat over 2 1/2 years, and a determined defendant often can add delay.) This puts an inventor in a poor bargaining position: grant a license, or wait at least 9 to 10 years to get anything from a lawsuit.[153]

In addition, other firms might seek patents for various improvements. This practice is very common in Japan. After an application is first published (generally 18 months after the application), firms frequently file many applications for improvements. Under Japanese law, a firm that receives a patent for an improvement can apply to the Patent Office for a compulsory license under the basic patent, if the owner of the basic patent refuses to agree on license terms. The Patent Office has discretion to grant or deny the request.[154] While this law has never actually been used, its presence can weaken the bargaining position of a patent owner.[155]

The Japanese system, which encourages licensing, might work well for Japan's economy by promoting diffusion of technology. However, it often does not serve U.S. firms well. To succeed at all in Japan, a U.S. firm might have to be the sole supplier of the item in question. As discussed elsewhere in this report, Japanese firms have a strong tradition and bias in favor of buying from

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149 19 U.S.C. 1337. This remedy was strengthened by the Omnibus Trade and Competitiveness Act of 1988, Public Law 1OO-418, Sec. 1342.

150 A GATT dispute resolution panel ruled in November 1988, upon the complaint of the EC, that Section 337 violates the ' 'national treatment'' clause of the GATT treaty, which requires that a member country treat imports from another member country in a reamer 'no less favorable than that accorded to like products of national origin in respect of all laws, regulations and requirements affecting their internal sale, offering for sale, purchase, transportation, distribution, or use. ' GATT Article H. The United States subsequently accepted the panel's ruling, making it an official GATT decision.

151 The Senate Committee on Commerce, Science, and Transportation, Subcommittee on Foreign Commerce and Tourism, has held hearings on the Japanese patent system on June 24, 1988 (Serial No. 100-59) and Feb. 28, 1989 (Serial No. 101-19).

152 Yoichiro Yamaguchi, patent attorney registered in Japan, Beveridge, DeGrandi & Weilacher, personal communication, Jan. 30, 1990.

153 Other delays are possible in both the Japanese and U.S. systems. The systems are hard to compare directly. In general, both systems involve similar types of delays (though sometimes in a different order), but the delays are longer in Japan. Ibid.

154 Japanese Patent Law, Law No. 121 of Apr. 13, 1959, as amended, Secs. 7292.

155 Yoichiro Yamaguchi, op. cit.

other Japanese firms. Japan's complex distribution system reinforces the preference for buying Japanese. An exclusive patented technology might be the only way for an American firm to get into the Japanese market if it is forced to license Japanese firms, they might capture the whole market.

The United States has been negotiating with Japan to fix these and other problems. Already, Japan has increased the Patent Office staff to reduce delay, although not nearly as much as the United States believes is necessary. Japan has also lengthened various deadlines for non-Japanese parties, to allow sufficient time for communication and translation. Because Japan is now producing many inventions, it might be receptive to granting stronger power to patentees to exclude competition. The *keidanren*, an influential Japanese association of businesses, has already urged that patent systems worldwide should provide "effective patent enforcement," including "preliminary and final injunctions [i.e., court orders against infringement] as well as monetary awards adequate to compensate patentees fully and serve as an effective deterrent."[156]

Critics of Japan's patent system might keep in mind that the U.S. system has its own drawbacks. Resolution of patent cases that go to trial is slow (on average over 2 1/2 years). In addition, patent litigation can be expensive, and our patent law is quite complex. Thus, foreigners may feel that our system puts them at a disadvantage. While patents are issued relatively quickly in the United States, they are fairly often ruled invalid by the courts. Moreover, 20 years ago the courts enforced patent rights more narrowly than they do now. It should therefore not be too surprising that Japan and other countries, following in our economic footsteps, do not grant as strong protection as we might wish.

Patent Office Procedures Worldwide

Procedures for issuing patents differ from one country to the next. This raises the cost of filing applications in more than one country. The United States has been negotiating in WIPO and with Japan and the countries of the EC on terms of possible harmonization. The negotiations have already borne fruit. At U.S. urging, Japan in 1988 started allowing inventors to put multiple claims (in effect, multiple variants of the same invention) in one consolidated application, as has long been the practice in the United States and Europe.

Most of the changes, however, will probably come only as part of a comprehensive settlement. As part of any package deal, it is likely the United States will have to change from a first-to-invent system (in which the first person to make an invention is entitled to a patent) to a first-to-file system (in which the first inventor to file an application is entitled to a patent). Only the United States and the Philippines follow the first-to-invent system.

A fret-to-file system has some advantages. Since patents disclose the invention, early patenting could increase technology diffusion. A fret-to-file system also avoids extensive legal fights over who was the first inventor. However, switching to a first-to-file system in this country could disadvantage small inventors (either individuals or startup or small firms), who are probably more important in the United States than elsewhere. Having no patent department, small inventors usually have a harder time filing applications and therefore prefer to delay filing, to see if the invention warrants filing and to have more time to prepare the application. Under a first-to-invent system, these inventors can delay filing applications without fear of being preempted. Under a first-to-file system, a small inventor might lose out to a later inventor in a large firm that gets its application filed first. This hardship on small inventors could be lessened by making initial applications easier and cheaper to file, as they are in many fret-to-file countries.

ANTITRUST LAW

Federal antitrust law prohibits a wide range of business conduct that restrains trade or monopolizes a market. Its core provisions, Sections 1 and 2 of the Sherman Act of 1890, as amended, prohibit both business "combinations . . . in restraint of trade" and the "monopoliz[ation], or attempt to monopolize," trade.[157] The Sherman Act and other antitrust statutes are worded in general terms, and could by their literal language prohibit a great deal of innocent business activity. The courts therefore have taken the statutes as an invitation to fashion a body

[156] The Intellectual Property Committee (USA), Keidanren (Japan), and UNICE (Europe), *Basic Framework of GATT Provisions on Intellectual Property: Statement of Views of the European, Japanese and United States Business Communities*, June 1988, p. 33.

[157] 15 U.S.C. 1-2.

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of precedent to explain more clearly what conduct is prohibited.

U.S. antitrust law has long been an effective shield against the power of monopoly and has kept many fields open to enterprising, innovative newcomers. Today, as foreign competition looms large in the U.S. economy, some have questioned whether traditional interpretation and enforcement of antitrust law may need some changes. Antitrust law could potentially prohibit firms from merging, forming joint ventures, and cooperating in various other ways—such as setting industry standards and conducting joint R&D projects. This section assesses the extent to which antitrust law might prohibit or discourage such behavior even when it would enhance the competitiveness of U.S. manufacturers.

While direct evidence is scanty, it appears that antitrust law does discourage some competitiveness-enhancing conduct, and would somewhat impede government and private efforts to increase such conduct. In most cases, the law does not actually prohibit the behavior in question; but because the law is unclear and involves stiff penalties, businessmen are often afraid to do anything that even looks like it might be an antitrust violation.

The Changing Interpretation of the Law

The types of conduct prohibited by antitrust law, and the philosophical justification for the prohibitions, have changed somewhat through the years. In the late 1800s and early 1900s, antitrust law was aimed in part at keeping businesses small. Small businesses were seen as more humane and more responsive to local needs. The Supreme Court, for example, criticized the transformation of "an independent businessman, the head of his establishment, small though it might be, into a mere servant or agent of a corporation, ''158 and noted the "widespread impression that corporate power had been and would be used to oppress individuals and injure the public generally.' '[159]

In recent years, antitrust law has been aimed not so much at preventing bigness as such but rather at ensuring fairly free competition. Under neoclassical economic theory, a free market-in which many firms compete and no one firm is large enough to affect the market for its product—is most efficient for society. When one or a small number of firms comes to dominate the market; those firms tend to reduce output and raise prices compared with free market levels. This market power is called oligopoly (if only a few firms are competing) or monopoly (if only one company sells the product).

Since the 1960s, the primary purpose of antitrust law has been to promote competition by minimizing the creation and exercise of market power.[160] Today both the courts and the Federal enforcement agencies acknowledge that some kinds of cooperation can often be justified by compensating benefits to society.[161] For example, suppose several competing firms with large combined market share in metal alloys create a joint venture to develop and sell a particular new alloy. Despite the joint venture's market power, society might be better off with the joint venture than without it because on their own the firms might have taken much longer to develop the product.

In evaluating a firm's conduct, enforcement agencies and the courts most often use a balancing test, or "rule of reason. " Conduct that threatens substantially increased exercise of market power is permitted if the societal benefits outweigh the societal costs (or, as sometimes phrased, if the pro-competitive effects outweigh the anti-competitive effects). The rule of reason is not always used. For example, certain egregious conduct, such as agreements among sellers to fix prices or divide markets, is deemed to be a *per se* (Latin for "by itself' violation. In such cases no balancing test is performed, on the ground that the conduct rarely if ever can have any social benefit.

The wide adoption of the rule of reason by the courts and the enforcement agencies has made antitrust law more accommodating than it once was.

[158] Frederick Rowe, "The Decline of Antitrust and the Delusions of Models: The Faustian Pact of Law and Economics," *Georgetown Law Journal*, vol. 72, June 1984, p. 1517, quoting *United States v. Trans-Missouri Freight Association,* 166 U.S. *290, 319, 323 (1987).*

[159] Ibid., p. 1517 footnote 32, quoting ***United States v. Standard Oil Co., 221*** U.S. 1, 50 (1911).

[160] Phillip Areeda and Louis Kaplow, *Antitrust Analysis: Problems, Text, Cases,* 4th ed. (Boston, MA: Little Brown & Co., 1988), pars. 111, 130, pp. 13-14, 44-45; Frederick Rowe, op. cit., pp. 1524-1535.

[161] *Report of the American Bar Association Section of Antitrust Law Task Force on the Antitrust Division of the U.S. Department of Justice,* July *1989, pp. 8-16.*

Congress also modified the antitrust statutes in the 1980s because of concern for U.S. manufacturing competitiveness. The Export Trading Company Act of 1982[162] provided for advance antitrust approval for firms working together through export trading companies. In the National Cooperative Research Act of 1984,[163] Congress mandated a rule of reason approach, and in some cases lessened penalties, for joint R&D. But whether these recent changes are enough, or whether further modification of antitrust law is called for to enhance U.S. competitiveness, is still an issue.

The Terms of the Debate

There are arguments for maintaining the status quo. In the past decade very few antitrust lawsuits have been brought, let alone won, that challenge activity which arguably should be encouraged on competitiveness grounds (e.g., joint R&D). [164] Moreover, it is hard to find examples of firms' giving up any such activity because of antitrust concerns.

In addition, antitrust enforcement has substantially lessened over the last two decades, especially in the early years of the Reagan administration. For example, civil cases filed by the Justice Department, around 30 per year in the late 1970s, dropped to the low teens by 1983. Cases against conduct other than price-fixing and bid-rigging[165] have become rare, and the Justice Department's guidelines, testimony and other public pronouncements often express a strong concern to ensure that antitrust law not prohibit desirable business activity. Private suits alleging antitrust conduct have also decreased in recent years—from about 1,110 cases filed in the 12 months ending June 30, 1984 to about 660 in the 12 months ending June 30, 1988. Further weakening of antitrust enforcement could send the wrong signal to business, and invite anti-competitive behavior.[166]

There are also arguments for further modification. One argument challenges the neoclassical premise that free markets always benefit society. Although the premise might be true generally, it does not apply in all cases. Specifically, perfect competition may not be conducive to innovation in today's business and technological conditions.

Firms will perform less innovation than would be best for society if they cannot capture substantial benefits of their innovations. In a perfectly free market, other firms imitate the innovator, take away some of the business, and drive the price down to a level that typically does not let the innovating firm recoup its investment. If the innovator can get market power, at least for a while, he can recover more of the value to society of his innovation. In the long run, a society in which innovators can expect to gain some market power, at least temporarily, is probably better off than one in which perfect competition always prevails.[167]

The patent system provides one way of gaining such market power. In fact, patent systems are usually justified on the ground that they encourage invention. A patent owner has the legal right to stop others from using the patented technology for a term of years (in the United States, generally 17 years), and this right often yields some market power, at least until others find a way around the patent.

Sometimes patents are not a very effective way of getting enough market power to repay an innovator (see the section Intellectual *Property* in this chapter). Corning out first with a new or improved product is an alternative way of achieving market power, at least for a time. But it is often the case today that neither patents nor the advantages of being first to market are enough to encourage adequate innovation by single companies. Increasingly, the kind of innovation nations need to enhance

162Public Law 97-290, 15 U.S.C. 4001 *et seq.*

163Public Law 98-4.62, 15U.S.C. 4301-4305.

164OTA is aware of no such cases, except that some cases have been filed (but not won) against groups of firms setting industry standards.

165Bid rigging involves the exercise of market power by buyers, which has undesirable effects similar to the exercise of market power by sellers.

166*Report of the American Bar Association Section of Antitrust Law Task Force on the Antitrust Division of the U.S. Department of Justice*, op.cit., pp. *4-5, 16-18, A7 (source* for chart on page A7 is U.S. Department of Justice, Antitrust Division Workload Statistics FY 1978 to FY 1987); *Annual Report of the Director of the Administrative Office of the United States Courts: 1988 (Washington, DC: U.S. Government* Printing Office, n.d.), pp. 181, 185; see also Patrick Marshall, "Do Antitrust Laws Limit U.S. Competitiveness?" Congressional Quarterly's ***Editorial Research Reports,*** vol. *2, No.* 1, July 7, 1989, pp. 368-70, The Reagan Administration did file a high number of criminal cases, but largely against small local businesses such as construction. *Report of the American Bar Association Section of Antitrust Law Task Force on the Antitrust Division of the U.S. Department of Justice,* op. cit., p. 17; Patrick Marshall, op. cit., p. 368.

167Thomas Jorde and David Teece, "Innovation, Cooperation and Antitrust: Balancing Competition and Cooperation,' *'High Technology Law Journal,* vol. *4, No.* 1, spring 1989, pp. 8-13,

competitiveness requires resources far beyond the means of small companies.[168] Even for very large firms, the expense and risks of R&D may be too great for the firms to go it alone. For example, both high definition television and optoelectronics require expensive technology development in several areas at once.

Capital costs for manufacturing can also be very high. It costs at least $250 million to build a plant to produce the present generation of DRAM semiconductors, and for the next generation capital costs will be much higher, perhaps $500 million per plant. Such costs may be too great for most U.S. firms to bear on their own. The manufacture of semiconductors and other high technology products also requires technical expertise in many fields-often beyond the capability of a single firm.

There are other reasons as well for cooperation among fins. Small manufacturing firms sometimes benefit from pooling their resources and bidding together on large jobs. Voluntary establishment of industry standards requires cooperation between firms. Sometimes mergers are necessary to match foreign fins' economies of scale.

All of these cooperative activities might run afoul of our antitrust laws. The law does not invariably prohibit activities like these. In fact, if firms can advance technology or otherwise improve their competitiveness only by teaming up, then courts may well judge that the benefits to competition outweigh the harm. Under the rule of reason, there would then be no antitrust violation. The trouble is that firms cannot be sure of this ruling in advance. Because elements of the law are vague, and the penalties for antitrust violation can be severe, firms often shy away from cooperative deals out of a combination of fear and ignorance.

Several factors can make it hard to predict the outcome of antitrust cases involving cooperation. Under the rule of reason, the beneficial and harmful effects of the deal must be compared. The harmful effects are determined largely by how much market power the deal creates, but in practice, market power is often very difficult to determine. For example, a proposed joint venture might be expected to sell 80 percent of laptop personal computers, but only 10 percent of all personal computers, in the U.S. market. The venture's vulnerability to antitrust will depend heavily on the extent to which laptops and other personal computers are substitutable. Even if the products do not readily substitute, some manufacturers of non-laptop personal computers might be waiting in the wings, ready to produce laptops if the joint venture tried to raise prices. In that case the joint venture would have little market power. In general, the substitutability of products and the ability and willingness of firms in neighboring fields to enter a market could be points of contention in court. Also in contention could be the deal's claimed beneficial effects. Will the firms substantially advance technology to develop a new product, or is the deal really just a front for pooling market shares? And is it really true that the individual firms could not profitably develop the product in question on their own?

How these points are resolved at trial again depends on several factors. The judge or jury may understand the need for firms to pool their resources but they may not. Facts about the market are hard to determine and are often the subject of conflicting expert testimony. Even after the facts are resolved, the weighing of positive and negative effects is not a precise calculation. It inherently involves the exercise of judgment.

In addition, while the rule of reason is widely used, alternative legal tests might in some cases cut short the full consideration of the activity's benefits. Antitrust doctrine contains the per se test (an activity is condemned without any consideration of its benefits), the "quick look" test (an activity's benefits are considered only if on a quick look it appears reasonably likely that such benefits exist); and the "least restrictive alternative" test (an activity is condemned if the court believes its benefits could have been achieved by another arrangement with less restrictive effect on competition). These doctrines might, for example, be applied to some joint production cases-especially if the

[168] According to the National Science Foundation, 200companies accounted for 90 percent of all industrial R&D spending in the United States in 1986. The *average* R&D spending among this group was $273 million. If the average R&D intensity of the firms was 10 percent (a very high figure) the 1986 average net sales for companies in this group were $2.7 billion. William L. Stewart, "Effects of Corporate Restructurings on R&D Support," testimony before the House Committee on Science, Space, and Technology, Subcommittee on Science, Research, and Technology, July 13, 1989.

[169] Jorde and Teece, op. cit., pp. 40-42, 47-48.

court is skeptical that joint production can yield benefits for society.[169]

These are some of the complex issues of fact and law that make the outcome of a particular case difficult to predict. They can also make a trial quite expensive. On the average, antitrust cases take longer than other cases filed in Federal district court. For example, of the cases that go to trial, antitrust cases take a median time of 35 months, compared with a median time of 19 months for all cases.[170] Firms therefore have reason to be cautious about activities that might be considered antitrust violations. The severe enforcement regime in antitrust law, which includes multiple enforcers and stiff penalties, reinforces caution.

Both the Justice Department and the Federal Trade Commission enforce Federal antitrust laws. These agencies can file civil suits to stop the offending conduct. Also, if the Justice Department establishes that an antitrust violation has caused economic harm to the government, the defendant must pay the government actual damages.[171] From 1984 to 1987 the Justice Department filed a total of 46 civil suits. Of the 50 civil suits terminated in that period, the government won 39, lost 2, and negotiated an agreement in the remaining 9.[172] For mergers and some joint ventures above certain dollar thresholds, firms must give the government advance notice.[173] If the government announces its intention to challenge the deal in court, the firms involved will usually either modify the deal to satisfy the government's concerns or abandon the deal altogether.

The Justice Department can also file criminal suits with potentially large fines for the corporation and culpable officers and employees, and imprisonment for culpable officers and employees,[174] although criminal suits have been reserved for egregious attempts to fix prices, divide markets, or rig bids. From 1984 to 1987 the Justice Department filed a total of 219 criminal cases. Of the 237 cases terminated in that period, 210 resulted in convictions.[175]

While the U.S. Government's civil enforcement in recent years has not been aggressive, firms are often reluctant to gamble that government policy will remain the same. Firms can seek approval in advance for a particular course of action from the Justice Department or the FTC,[176] but these approvals often take several months and can involve considerable legal expense. Firms usually save this process for substantial projects (justifying high legal fees) that can wait several months. Also, government approval does not insulate firms against private suits, though in practice it lessens the likelihood that private suits will be filed or will succeed.

Private parties can file antitrust suits if they claim to be threatened or to have suffered some economic harm caused by an alleged violation. Private suits are far more numerous than government suits. In the 12 months ending June 30, 1988, private parties filed about 660 private antitrust suits in Federal court, compared with 20 civil and 70 criminal cases filed by the government.[177] Private suits are on average

[170] *Annual Report of the Director of the Administrative Office of the United States Courts: 1988,* op. cit., pp. 220, 221.

[171] See 15 U.S.C. *4, 15a, 25. The* Federal Trade *Commission* proceeds under 15 U.S.C. 21 (mergers) or under the Federal Trade Commission Act, 15 U.S.C. 45.

[172] U.S. Department of Justice, Antitrust Division Workload Statistics 1978 to FY 1987, reprinted *in Report of the American Bar Association Section of Antitrust Law Task Force on the Antitrust Division of the U.S. Department of Justice,* op. cit., p. A7 (total civil cases: filed, won, lost, dismissed).

[173] 15 U.S.C. 18a.

[174] 15 U.S.C. 1.

[175] U.S. Department of Justice, Antitrust Division Workload Statistics FY 1978 to FY 1987, reprinted *in Report of the American Bar Association Section of Antitrust Law Task Force on the Antitrust Division of the U.S. Department of Justice,* op. cit., p. A8 (total criminal cases: filed, terminated, won). In 1987,42 individuals were fined a total of $1,636,000; 15 individuals were sentenced to serve time in jail and 33 more were given probation; 1,994 jail days were served; and 66 corporations were freed a total of $16,265,000. Ibid., reprinted in *Report of the American Bar Association Section of Antitrust Law Task Force on the Antitrust Division of the U.S. Department of Justice,* op. cit., pp. A11-A13.

[176] Neither Justice Department approvals nor FTC staff level approvals are binding on the government, but no firm has ever been sued for conduct within the scope of such an approval. Janice Rubin, Library of Congress, Congressional Research Service, American Law Division, "The Impact of U.S. Antitrust Law on Joint Activity by Corporations: Some Background," May 1, 1989, p. 7 (Department of Justice); Carl Hevener, Justice Department Liaison, Federal Trade Commission, personal communication, Dec. 1 and 5, 1989 (Federal Trade Commission). During 1984-87, the Justice Department received about 25 requests for approval per year and granted roughly 90 percent of them. U.S. Department of Justice, Antitrust Division Workload Statistics FY 1978-1987, reprinted in *Report of the American Bar Association Section of Antitrust Law T&k Force on the Antitrust Division of the U.S. Department of Justice,* op. cit., p. A5 (business reviews),

[177] *Annual Report of the Director of the Administrative Office of the United States Courts:* 1988, op. cit., pp. 181, 260.

less successful than government suits, although the statistics are somewhat unclear.[178]

Private parties that bring suit are usually either customers or competitors. If the suit is successful, the offending conduct must stop and the offender must pay to the complaining party: 1) treble damages, i.e., three times the amount of economic harm the complaining party can show he suffered,[179] and 2) the reasonable cost of the complaining party's attorneys for the successful claims. These are severe penalties. In most other areas of U.S. law, a complaining party, if successful, is entitled only to single damages, i.e., the actual amount of harm he shows he has suffered, and is usually not entitled to reimbursement of the expense of hiring attorneys.

The prospect of treble damage and attorney fee awards can encourage lawsuits by competitors and customers. Even if the defendant believes he could probably win in court, the prospect of paying these large awards—as well as the time and money needed to fight the case-might scare him into paying something to settle the case, and someone contemplating filing a suit knows this.[180]

Antitrust laws may be enforced by State governments as well. Under Federal antitrust law, State governments may file civil suits on behalf of their citizens--e.g., on behalf of a large class of consumers who allegedly paid excessive prices because of an antitrust violation. The penalties are the same as if the citizens themselves had filed suit.[181] State governments also can enforce the State's own antitrust laws, if the State has any.

In sum, even if antitrust law does not usually condemn activities outright that could improve manufacturing competitiveness, it can often discourage such activities. For large firms, able to get expert legal advice, antitrust risk is often considered as one factor among many. Cooperative projects have ordinary business risks as well. Will the technology work? Will the market be there? Antitrust adds another risk, and makes the project that much less desirable. Similarly, the need to pay for a legal analysis of the antitrust risk and for ongoing legal supervision adds to a project's cost at various stages. For small fins, often unable or unwilling to pay for legal advice, antitrust fear is more likely to act as an absolute bar. If a small firm suspects that a project involves antitrust risk, it might drop the idea immediately-even if there is no real risk. The ambiguity and complexity of antitrust law are therefore particularly troublesome to small firms.

While the chilling effect of antitrust is plausible, it is hard to tell how important it is compared with other factors that discourage cooperation. It is difficult to find examples in which antitrust actually killed a cooperative project, and the examples given here are not overwhelming. More telling examples may exist. Firms might hesitate to offer them because word of their actual or contemplated activities could provoke suits or give away strategic information to competitors. More important, business decisions typically depend on many factors, and it is hard even for those involved to say whether fear of antitrust changed a decision. A businessman sensitized to antitrust concerns might even avoid or quickly abandon ideas for cooperative projects. Those ideas will never be counted or noticed as activity discouraged by antitrust.

Some activities-e. g., R&D consortia, joint manufacturing, and resource pooling by small firms—have only recently received serious attention in government and industry as ways to enhance competitiveness. Even if antitrust in the past has not visibly discouraged very much activity, it might do so more in the future as more of these projects are proposed.

[178] Of the 891 private antitrust suits terminated in the 12 months ending June *30, 1988, 145 are* listed as "settled," 434 ss "other dismissed,"64 ss ''other non-judgment, ' and 248 as going to judgment by the court. Of those 248,67 are listed as "for plaintiff, " 143 ''for defendant, " and 38 "other." David Gentry, Statistical Analysis and Reports Division, Administrative Office of the U.S. Courts, personal communication, Dec. 7, 1989. It appears that at least 577 cases ("otherdismissed" plus ''judgment for defendant' went entirely for defendant, and that in 212 cases (' 'settled' plus 'judgment for plaintiff'') plaintiff recovered something.

[179] Only single damages are paid in suits concerning R&D projects registered under, and within the scope of, the National Cooperative Research Act of 1984, discussed below.

[180] Statistics for the 12 months ending June 30, 1988 show 145 private antitrust suits ''settled'' out of 891 terminated, or 16 percent. David Gentry, Statistical Analysis and Reports Division, Administrative Office of the U.S. Courts, personal communication, Dec. 7, 1989. However, some cases where some settlement was paid might be reported under a different heading.

[181] 15 U.S.C. 15c.

Effect on Business Activity

Joint Research and Development

Traditionally, joint R&D has posed relatively little antitrust risk. Such projects offer obvious potential benefits in spreading risks and improving firms' efficiency and competitiveness. Moreover, member firms are generally free to manufacture and market products on their own (although there might be agreements restricting use of the resulting technology). Experts in the field know of no antitrust case brought against genuine joint R&D, and the Justice Department acknowledges that "[a]s a general matter, joint R&D activities can have substantial procompetitive effects." [182]

The National Cooperative Research Act of 1984 lessened the legal risks of joint R&D.[183] First, the Act provides that such activity will always be judged by the rule of reason, balancing its beneficial and harmful effects.[184] While joint R&D would in general have been judged by the rule of reason anyway, this provision did remove some uncertainty and sent a signal from Congress that cooperative R&D can yield important benefits. This probably increased judges' sensitivity to the benefits in balancing the pro- and anti-competitive effects of joint R&D.

The Act also provides that, for joint R&D projects registered promptly for publication in the Federal Register, only actual damages (rather than treble damages) may be awarded in a private lawsuit. (Attorney fees can still be awarded.) [185] As of January 1990, 160 separate projects had filed 323 registration statements including amendments.[186] Some of these projects probably would not have gone forward without the 1984 Act.[187] Registration greatly reduces the financial exposure in undertaking joint R&D and by the same token greatly reduces the incentive for parties to file private suits. The Act further discouraged indiscriminate private suits by providing that one who files a private suit breed on a claim that is "frivolous, unreasonable, without foundation, or in bad faith" must pay attorney fees of the accused party.

One consortium registered under the Act is the National Center for Manufacturing Sciences (NCMS), which started operations in 1987 and by 1990 included over 100 manufacturing firms.[188] The membership encompassed large firms such as General Motors and AT&T; smaller firms such as Kinefac Corp., a 70-employee metalworking firm in Worcester, Massachusetts; and even some firms with fewer than ten employees. (Many of the smaller firms joined at the urging of their larger customers.)

It is not clear whether NCMS would have been formed without the 1984 Act. Even with the Act, antitrust has been a major concern for present and prospective members. In its startup period, through early 1989, NCMS spent about $200,000 for antitrust advice from a law firm. In the organizations' first months, the director of NCMS spent most of his time on antitrust issues. NCMS's early meetings were devoted largely to antitrust concerns, and into early 1989 NCMS was still receiving about two queries a week from members. Antitrust concerns have gradually lessened as 1)NCMS became familiar with the issues and could more easily address members' concerns, 2) members noted that no firm had been sued for R&D registered under the 1984 Act, and 3) competition became more intense and the benefits of joint R&D became more apparent, so that members were willing to accept some antitrust risk.

Before joining NCMS, most members were not in the habit of sharing technical discussions or R&D-partly from unfamiliarity, partly from antitrust fear. NCMS has discovered that its members' pressing R&D concerns overlap considerably, so that coopera-

182 U.S. Department of Justice, Antitrust *Enforcement Guidelines for International operations,* Nov. 10, 1988, p. 56.

183 Public Law 98-462, 15 U.S.C. *4301-$305.* There are some limitations, discussed below, on what constitutes joint R&D under the Act.

184 The Act requires that the rule of reason also be used in judging joint R&D under State antitrust law.

185 The Act similarly limits damage awards in cases based on State antitrust law.

186 U.S. Department of Justice representative, personal communication Feb. 1, 1990, The first 125 or so projects are described in "National Cooperative Research Act of 1984 Consortia," New *Technology Week, Special* Supplement, June 12, 1989.

187 *The Government Role in Joint Ventures,* hearing before the House Committee on Science, Space, and Technology, Sept. 19, 1989, Serial No. 101-58, testimony of Mauro DiDomenico, director, technical liaison office, Bellcore, p. 101; and testimony of Peter Mills, chief administrative officer, Sematech, p. 122.

188 The material on NCMS comes from Ed Miller, Director, NCMS, personal communication, Apr. 10 and 27, May 3, Aug. 5, Sept. 6, 1989, and Jan. 29, 1990; and Patrick Ziarnik, counsel, NCMS, personal communication, Jan. 26, 1990.

tive R&D can yield substantial savings. One example is R&Don laser beam splitting-i. e., how to use one laser beam for several processes at once. NCMS also facilitates informal technical exchanges among members—for example, while discussing whether to fund proposed projects.

NCMS has sometimes made matches between companies with complementary abilities. It did so, for example, in the development of ductile iron as an inexpensive substitute for structural steel in the non-moving parts of machine tools. A consulting professor had recommended the alternative of ductile iron, but NCMS could not find any U.S. company that could both design the specialized molds needed for pouring the iron and do the pouring. NCMS then brought together firms with the CAD ability to design the molds and a company that could pour the ductile iron once it had the molds. The effort cost NCMS about $50,000. It has saved one NCMS member about $250,000.

Although the 1984 Act lessened fears of antitrust suits arising from joint R&D, these fears have not completely vanished—as shown, for example, by the continuing concern of NCMS' members. Also, the Commerce Department has from time to time provided a "safe house" in which competitors afraid of prosecution for merely discussing a possible R&D collaboration could frost come together to hold discussions under government supervision.[189] The concerns are understandable. Even firms that register their projects may still be sued by the government or by private parties for single damages and attorney fees. Firms that prefer to maintain secrecy and do not register are subject to private treble damages. Even under the rule of reason the firms are not necessarily home free. For example, the Justice Department's 1980 guidelines for joint research ventures state that "[a] joint venture between directly competing companies in a highly concentrated industry . . . will be subject to very close antitrust scrutiny."[190]

In cases where cooperating firms need to exchange cost and marketing information in order to guide the project in a commercially useful direction, the 1984 Act covers such exchanges only when "reasonably required to conduct the research and development." If, despite the firms' belief that certain communications were necessary, a court should hold otherwise, then those communications would not be protected by the Act's provisions.

Also, the Act covers manufacturing only for "experimental and demonstration purposes. ''191 Sometimes sizable runs are needed to demonstrate a process, and the firms involved would take a significant loss if they could not sell the items produced. Yet a court might rule that such sale is not covered by the Act.

More fundamentally, the Act does not cover commercial manufacturing. Yet there may be cases in which the scale of the enterprise needed to capitalize on R&D is beyond the means of single fins.

Joint Manufacturing

Joint manufacturing can sometimes make firms more competitive, for example, by allowing economies of scale in production. This could be especially important in fields such as semiconductors where a production facility costs hundreds of millions of dollars. Firms might sometimes need to share technical as well as financial resources. Manufacturing, like R&D, often requires expertise in many fields. Again, semiconductor fabrication offers an example. Future examples might be devices based on optoelectronics or high temperature superconductivity. Sharing both financial and technical resources can mean the difference between being first to market or being an also ran.

Joint manufacturing can have another sort of benefit when it follows joint R&D performed in a central organization. Technology transfer from that central organization back to the member companies can be difficult. It might be easier for the central organization to proceed with manufacturing. For example, some say that it is unfortunate that Sematech will not perform commercial manufacture (see the section in this chapter on R&D consortia). Innovation ideally consists of repeated feedback

[189] Lansing Felker, Director, Industrial Technology Partnership Program, U.S. Department of Commerce, personal communication, Mar. 3, 1989.

[190] U.S. Department of Justice, *Guide for Research Joint ventures* (1980), Illustrative Examples, Case *B—red* Research and Development Joint Venture in Concentrated Industry, reprinted in *Trade Regulation Reports* par. 13,120 (Commerce Clearing House 1988), While these guidelines might be somewhat outdated in view of the more liberal tone of the U.S. Department of Justice, *Am"trust Enforcement Guidelines for International Operations (1988),* p. *56,* the 1980 guidelines were relied on by NCMS' antitrust counsel in 1989 in giving cautious advice regarding a proposed project.

[191] 15 U.S.C. 4301 (a)(6)(C).

between R&D, design, manufacturing, and marketing. Many rounds of feedback between a joint R&D venture and its members might be much more difficult than many rounds of feedback would be within a venture that did both R&D and manufacturing.

In general, joint manufacturing carries more antitrust risk than joint R&D, because it can directly reduce competition. When firms manufacture jointly, purchasers may have fewer choices of products and suppliers. However, in some risky high technology ventures, joint manufacturing might be the only way to encourage new entrants. High-definition television (HDTV) offers an example of antitrust concerns in manufacturing joint ventures. Starting in early 1989, the American Electronics Association (AEA) sought to promote R&D and manufacturing consortia for HDTV. During the first several months, AEA had trouble even getting firms to talk with each other, largely because of antitrust fears. Antitrust then became less of a concern—partly because the firms with AEA's help were able to think through the antitrust issues, and partly because the many congressional hearings on possible changes in antitrust law made it seem likely that Congress would amend the law, or at least that enforcement agencies and the courts would interpret the law with more appreciation of the benefits of joint production.[192]

Some analysts question whether U.S. firms really need large joint manufacturing ventures, arguing that Japanese firms have done very well without them. Even if Japanese firms do not do much joint manufacturing (and this point is subject to dispute), the two countries are not the same. Japanese firms are much better able to finance large manufacturing projects on their own (see ch. 3). They also sometimes have a wider range of in-house technological expertise.[193] In addition, Japanese high technology firms are sometimes protected against foreign competition-either by the government or by customers who buy Japanese products preferentially.

Antitrust concerns can also discourage small manufacturing firms from cooperating in marketing and in performing jobs that are too big or require too many specialized capabilities for the firms to handle on their own. Japanese manufacturing firms cooperate a great deal in this manner, with the blessing and active encouragement of their government; some European firms have done so as well (see ch.6). Some U.S. industry groups, encouraged by the Commerce Department, are seeking to increase such cooperation in this country.[194] Antitrust concerns seem to have impeded these efforts somewhat.[195]

An example comes from the Flint River Project, Inc., a subsidiary of Efficient Enterprises, Inc., in Troy, Michigan. In 1988, Flint River began trying to form a network of small manufacturers of spare parts for automobiles, heavy equipment, and defense. Flint River proposed to market the fins' products domestically and abroad by finding jobs to be done, selecting a suitable team of firms for each job, and performing any needed technical coordination, including design and project management. The network still had not formed as this report was written. While antitrust was not the only problem, it was a significant one. The firms were afraid that participating in such a network could be deemed an antitrust violation--e.g., a conspiracy to fix prices.[196]

Another example: in the early 1980s, a few members of the Milwaukee chapter of the National Tooling and Machining Association discussed a bid solicitation from the U.S. Department of Defense for about 40 million dollars' worth of special-purpose carts to transport bombs. The members believed that by combining their production capacities and their various specialized abilities (such as welding, precision manufacturing, design, and possession of a large crane) they could do the job as well as and much more cheaply than traditional large defense contractors. However, early in the discussions some-

[192] Pat Hill Hubbard, Vice president, EIA, personal communication, Sept. 8, 1989.

[193] GmgoV Tm.y,6'SncW~ Change and Competitiveness: The U.S. Semiconductor Industry, '' *Technological Forecasting and Social Change*, vol. *38*, 1990 (forthcoming); Richard Elkus, chairman, Prometrix Corp., personal communication. Dec. 1 and 7, 1989 (electronics industry).

[194] Theodore Lettes, Office of Technology Policy, U.S. Department of Commerce, personal communication, May 3, Sept. 7, 1989.

[195] Robert Friedman, "Flexible Networks and Antitrust," *The Entrepreneurial Economy Review*, vol. 7, No. 9, May 1989 (published by the Corporation for Enterprise Development, Washington, D.C.).

[196] Michael Hasler, president and chief executive officer, Efficient Enterprises, Inc., Troy, MI, personal communication, Apr. 26, May 3, and Sept. 14, 1989, and testimony at hearings before the House Committee on Small Business, Subcommittee on Regulation and Business Opportunities, Sept. 13, 1988, Serial No. 100-74, pp. 125-28.

one mentioned antitrust, and as a result the idea was quickly dropped.[197]

In neither of these two examples was the fear based on a legal analysis of the particular circumstances. Rather, the firms' managers said in effect at the outset, 'This might have antitrust problems, and I can't afford a lawyer to find out. Unless I somehow get assurances that there will be no problem, I won't proceed."

Standards-Setting

Voluntary industry standards are necessary for industrial efficiency. Without them, for example, light bulbs would not fit into sockets and regional telephone networks could not exchange information. However, it is possible for a standards-setting association to be dominated by a clique of firms that use the process of establishing standards to shut other firms out. For example, a clique might develop standards in secret, so that their competitors would not be able to conform their products to the standard promptly. In addition, a clique might pick one standard not because it is the best, but because it is difficult for competitors to meet. Such practices would probably be deemed antitrust violations, as well they should be.[198]

However, even if firms perform standards-setting with no anti-competitive intent, other firms may nevertheless file an antitrust suit claiming that the standard somehow unfairly discriminated against them. A court might take these claims seriously. The Supreme Court recently stressed that standards-setting can easily be abused to harm competition:

> [T]he members of [standards-setting] associations often have economic incentives to restrain competition and . . . the product standards set by such associations have a serious potential for anticompetitive harm. . . . Agreement on a product standard is, after all, implicitly an agreement not to manufacture, distribute, or purchase certain types of products.[199]

To forestall accusations, many U.S. associations have adopted elaborate procedural rules for setting standards, including open meetings at which all firms are free to express their opinion. According to Bell Communications Research (Bellcore), these open meetings are cumbersome and can slow down adoption and implementation of standards. In fast-moving fields such as telecommunications, delay might mean missed opportunities and reduced competitiveness. Firms could speed up progress by also meeting informally in smaller groups to iron out difficult technical problems; however, they are reluctant to do so for fear of an antitrust lawsuit.[200]

This problem arose in connection with communication standards for ways in which telephone networks in different regions or countries can exchange various information--e. g., route calls around congested lines, determine whether a called party's line is busy, and verify credit card numbers. These standards are handled by the T1.S1.3 Working Group (formerly the T1.X1.l Working Group) of the T1 Standards Committee, which is accredited by the American National Standards Association. According to Gary Schlanger, that working group's chairman for 1984 to 1987, U.S. and foreign approaches to exchanging such information started to diverge in 1986. The working group's efforts to resolve those differences and harmonize the U.S. and international practice were deadlocked for 2 years. Mr. Schlanger believes that with smaller, informal meetings harmonization could have been achieved. Instead, in 1988, the T1 Standards Committee adopted a U.S. standard inconsistent with the international standard used by the rest of the world. Now U.S. equipment manufacturers and phone companies must cope with translating between the U.S. standard and the world standard.[201]

Joining *Forces* Against Foreign Firms

In some cases, a fragmented U.S. industry faces competition from a much more powerful foreign industry. By combining forces, the U.S. firms might achieve similar advantages and hold their own. But some mergers or joint ventures between U.S. firms, each of which hold substantial shares of the same

[197] Carl Edquist, President, Carlson Tool & Manufacturing Co., Cedarburg WI, personal communication, Apr. 28, 1989.

[198] See for example *Radiant Burners, Inc., v. People's Gas, Light and Coke CO.*, 364 *U.S. 656* (1961).

[199] *Allied Tube & Conduit Corp. v. Indian Head, Inc., 108 S.* Ct. 1931, 1937 *(1988).*

[200] Joe Klein, General Attorney, Bellcore, personal communication, Ma,3 and Sept. 13, 1989; Mauro DiDomenico, director, technical liaison office, Bellcore, testimony at hearings before the House Committee on Science, Space, and Technology, Subcommittee on Science, Research and Technology, Sept. 19, 1989, Serial No. 101-58, pp. 106-109.

[201] Gary Schlanger, Division Manager, Carrier Interconnections, Standards, and Numbering Plan Management Department, Bellcore, personal communication, Sept. 15, 1989.

market, are either blocked or never attempted because of antitrust law. Under the Justice Department's Merger Guidelines, the firms involved must provide a high level of proof of any claimed benefits. Also, the Department will consider whether similar benefits could be achieved by other means.[202] One merger blocked by the Department was the attempt of BTU International, a manufacturer of furnaces used to produce semiconductor chips, to purchase Thermco, a subsidiary of the Allegheny Corp. (box 7-E). While the Justice Department in this case may have simply followed judicial precedent and the Merger Guidelines, these rules may be out of tune with the realities of failing U.S. competitiveness.

Overall, the uncertain cost of keeping antitrust law as it is today must be measured against the uncertain cost of proposed changes. Several possible modifications would leave intact the basic doctrine of antitrust law and the basic enforcement machinery, but would adjust around the edges. For example, points of law could be clarified; safe harbors and advance approvals could be provided; and treble damages could be reduced in some cases to single.[203] It is not clear that changes such as these would spark significant anticompetitive activity, particularly in light of today's economic conditions. On the whole, it is harder to maintain market power today than it was earlier in the nation's history. In some fields, products and processes have shorter life cycles so today's monopolist might find his position eroded tomorrow by competitors' new technology. Most significantly. foreign firms are more likely than ever before to compete against U.S. firms that try to raise prices above competitive levels.

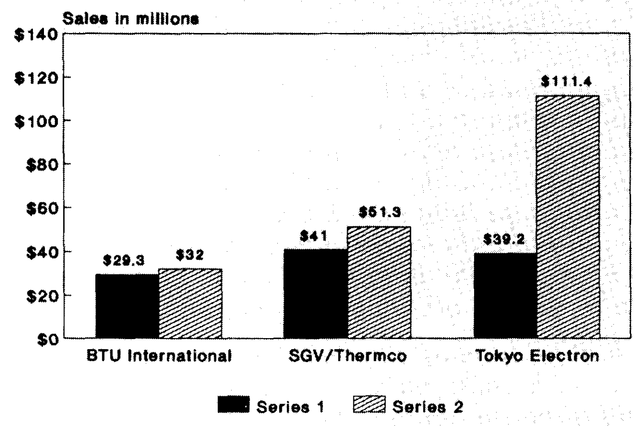
202 U.S. Department of Justice, "Merger Guidelines," June 14, 1984, sec. 3.5, pp. 35-36.

203 These and other proposals are discussed in ch 2.

Box 7-E—BTU Feels the Heat[1]

In 1987, BTU International began negotiations with Allegheny Corp. to buy its subsidiary Thermco Inc. At that time, BTU and Thermco together accounted for as much as 93 percent of all U.S. sales of hot-wall oxidation/diffusion furnaces, equipment essential to the manufacture of semiconductor chips.[2] In February 1988, BTU and Thermco filed their intent to merge with the Justice Department. BTU hoped that the acquisition would give it sufficient economies of scale, marketing power, and R&D capability to fend off expected competition from the principal Japanese manufacturer of this equipment, Tokyo Electron (TEL). In May 1988, the Justice Department determined that such a merger would give BTU a monopoly position in the U.S. market and denied approval of the merger. Instead, Thermco was bought by the Silicon Valley Group (SVG). Less than 2 years later, interviews with diffusion furnace manufacturers indicate TEL is on the verge of capturing nearly a quarter of the U.S. market;[3] and within a few more years it might have fully half. The U.S. firms are finding it difficult to compete with the much larger TEL. Executives at BTU and its rival U.S. firm SVG agree that overall the U.S. manufacturers would be in a stronger position to compete with TEL if BTU had been permitted to buy out Thermco, gaining advantages that neither alone can achieve.[4]

World Diffusion Furnace Sales



SOURCE: VLSI Research Inc., 1989.

SVG's Chief Financial Officer, Bob Muller, and BTU's CEO, Paul van der Wansem, explain that when the merger application was pending before the Justice Department, two factors presaged the rise of TEL in the U.S. market. First, TEL's products were already the industry standard for Japanese chipmakers. As Japanese manufacturers established fabrication plants in the U.S., they brought with them their commitment to TEL products. Included on this list are Toshiba's plant in Sunnyvale, California; Hitachi's in Texas; Mitsubishi's in North Carolina; and Fujitsu's in Oregon. Second, and more significant in terms of U.S. market share, U.S. chipmakers had begun to import their process technology from Japan. To maximize the chances that the imported process will give the same high yield in the U.S. facility as it did in the Japanese plant, a U.S. licensee would normally buy the same furnaces. In particular, Motorola, which licensed 1 and 4 megabit DRAM process technology from Toshiba, was expected to use TEL equipment in its new $400 million plant in Austin, Texas.

The Justice Department was aware of these considerations but came to a different conclusion. The Justice Department believed that TEL was unlikely to gain enough market share to prevent monopoly pricing by a merged BTU and Thermco within the 2-year time limit usually used to evaluate future competition. Interviews with diffusion furnace purchasers indicated to the Justice Department that brand loyalty in this type of product was so great that market penetration for a new firm would be extremely difficult. After talking to Motorola, the Justice Department decided that Motorola's expected purchase of TEL equipment was an exceptional case based on "special business conditions" (i.e., Motorola's use of Toshiba's process technology). The Justice Department also decided that the Japanese chip manufacturers who were building plants in the United States and importing their

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[1]This section is based on information from the following personal communications: Paul van der Wansem, CEO, BTU International, November 2, 1989; Paul O'Donnell (the lawyer representing BTU to the Department of Justice), Ropes and Gray, January 18, 1990; Bob Cole, President, Varian-TELLtd., December, 1989; Anthony Muller, CFO, Sillicon Valley Group, December 5, 1989; Ken Phillips, Public Relations, Motorola, December, 1989; Bob England, Vice-President, Semiconductor Group, Texas Instruments, January 26, 1990; Representatives of the Department of Justice, December 13, 1989, and January 31, 1990.

[2]According to market share data gathered by Dataquest and filed by Thermco with the Justice Department, BTU had 46 percent and Thermco 47 percent. BTU, defining product categories differently, filed data showing much lower market shares.

[3]While no hard figures are available, the estimates by TEL's U.S.distributor and TEL's U.S. competitor, BTU, agree.

[4]Muller points out that Thermco has increased its market share since its purchase by SVG, so SVG is not really unhappy with the Department of Justice's ruling. Nevertheless, he concedes that the overall strength of U.S. manufacturers in this field, and their ability to resist Japanese entry into the American market, would have been greater if BTU and Thermco had combined forces.

old loyalty to TEL equipment did not represent a sufficiently large share of the market to prevent BTU from gaining a monopoly position.

Immediately after BTU's takeover effort failed, the Silicon Valley Group approached Thermco and was allowed to buy the firm without ado. SVG makes other types of semiconductor production equipment and had previously attempted and failed to enter the diffusion furnace business. Although BTU's market share in the United States is currently larger than TEL's, SVG sees TEL and not BTU as its principal competitor. TEL's 1988 world sides of diffusion furnaces were bigger than the combined world sales of BTU and SVG, making it the world giant.

Though it is impossible to know for certain what the results of a BTU/Thermco buyout would have been, the following seem likely: BTU and Thermco could have combined their current technological strengths, improving production of the most advanced systems; BTU and Thermco combined could have significantly increased their R&D by eliminating duplication; and the increased size of a united BTU/Thermco would have allowed the companies to realize savings in production, marketing, and administration. Whether such advantages could have slowed or stopped TEL's penetration of the U.S. market cannot be known for sure. Further, the beneficial effects of the merger might not have been as great as originally hoped.[5] But both BTU's van der Wansem and SVG's Muller think that combination would have been stronger than the current U.S. configuration of BTU on its own and SVG with Thermco, In this case, the Department of Justice's refusal to permit the merger seems to have hampered the competitiveness of the U.S. manufacturers.

[5] Thermco did not want to be acquired—both because BTU had been an archrival and because layoffs were bound to result as the tWO operations were meshed. SVG's Muller suggests that enough key personnel might have quit that BTU would have acquired only the hollow shell of Thermco.

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