Chapter 2

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

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## *Boxes*

# 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.

12For 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,

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[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.

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

33 According 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.

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

35 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); *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.*

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[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). Charle Blaschke 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, in 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. 371O(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 and 4 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.

[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, anthe 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

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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.

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

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

9MIT 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.

10Ibid., 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-

86The 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.