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SCIENCE, TECHNOLOGY AND ECONOMIC GROWTH

by

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My primary concern in this paper will be with certain aspects of the so-called high technology industries that are, I believe, highly relevant to America's economic growth prospects. The most direct way in which these aspects are relevant to economic growth is that they directly affect the country's ability to maintain or to improve its competitiveness in world markets. The term "science" appears in the title of this paper because the high technology industries with which I will be primarily concerned are, by common definition, those in which scientific inputs loom large - whether these inputs are measured in terms of the number of scientifically trained personnel or expenditures upon research and development (R&D).

The two features that I will be mostly concerned with are: (1) The increasing extent and the increasing speed with which certain new technological capabilities are being transferred, not only between industries, but among countries as well; and (2) the rising costs of development (the D of R&D) in the high technology industries. These two features carry with them some important implications for America's competitive position which I will discuss later in the paper.

TABLE I

Company and federal funding of industrial R&D for selected industries: 1971-1981

Industry	Total 1971	Total 1981	Federal 1971	Federal 1981	Company[1] 1971	Company[1] 1981
	Millions of current dollars					
Total	$18,320	$51,830	$7,666	$16,468	$10,654	$35,352
Chemicals and allied products	1,832	5,325	184	383	1,648	4,942
Industrial chemicals	1,009	2,553	159	367	850	2,186
Drugs and medicines and other chemicals	823	2,770[2]	25	20[2]	798	2,756
Petroleum refining and extraction	505	1,920[2]	17	140[2]	488	1,777
Rubber products	289	800[2]	69	190[2]	221	616
Primary metals	272	889	6	182	266	707
Ferrous metals and products	144	560[2]	2	140[2]	142	414
Nonferrous metals and products	128	330[2]	4	40[2]	124	293
Fabricated metal products	242	638	11	80	230	558
Nonelectrical machinery	1,860	6,800	315	739	1,545	6,061
Electrical machinery	4,389	10,466	2,258	3,962	2,131	6,502
Communication equipment and electronic components	2,731	6,396	1,479	2,167	1,252	4,228
Motor vehicles and other transportation equipment	1,768	5,089[2]	309	704[2]	1,461	4,381
Aircraft and missiles	4,881	11,702	3,864	8,501	1,017	3,201
Professional and scientific instruments	745	3,685	164	638	583	3,047
Scientific and mechanical measuring instruments	133	1,680[2]	14	400[2]	120	1,285
Optical, surgical, photographic, and other instruments	612	2,000[2]	150	240[2]	463	1,762
All other manufacturing industries	2,889	8,325[2]	395	963[2]	2,494	7,358
Nonmanufacturing industries	704	2,080[2]	452	880[2]	252	1,199
	Millions of constant 1972 dollars[3]					
Total	$19,081	$26,511	$7,984	$8,423	$11,097	$18,087
Chemicals and allied products	1,908	2,724	192	196	1,716	2,528
Industrial chemicals	1,051	1,306	166	188	885	1,118
Drugs and medicines and other chemicals	857	1,410[2]	26	10[2]	831	1,410
Petroleum refining and extraction	526	980[2]	18	70[2]	508	909
Rubber products	301	410[2]	72	97[2]	230	315
Primary metals	283	455	6	93	277	362
Ferrous metals and products	150	290[2]	2	70[2]	148	212
Nonferrous metals and products	133	170[2]	4	20[2]	129	150
Fabricated metal products	252	326	11	41	240	285
Nonelectrical machinery	1,937	3,478	328	378	1,609	3,100
Electrical equipment	4,571	5,353	2,352	2,026	2,220	3,326
Communication equipment and electronic components	2,844	3,272	1,540	1,108	1,304	2,163
Motor vehicles and other transportation equipment	1,841	2,602[2]	322	360[2]	1,522	2,241
Aircraft and missiles	5,084	5,985	4,025	4,348	1,059	1,637
Professional and scientific instruments	777	1,885	171	326	607	1,558
Scientific and mechanical measuring instruments	139	860[2]	15	210[2]	125	657
Optical, surgical, photographic, and other instruments	637	1,020[2]	156	120[2]	482	901
All other manufacturing industries	3,009	4,260[2]	411	490[2]	2,598	3,769
Nonmanufacturing industries	733	1,060[2]	471	450[2]	262	613

[1]Includes all sources other than the Federal Government.

[2]Estimated.

[3]GNP implicit price deflators used to convert current dollars to constant 1972 dollars.

SOURCE: National Science Foundation, *Research and Development in Industry, 1980* (NSF 82-317), pp. 11, 14, and 17, and National Science Foundation, preliminary data.

See table 4-2 in text.

low-tech, "metal-bending" industry, this is very far from the present-day reality. Automobiles that come off today's assembly lines incorporate highly advanced metallurgy and numerous electronic controls. The electronic componentry in the average American car has increased from $300 to $900 in just a few years. The automobiles embody designs that were achieved by computer simulation techniques and the manufacturing process now makes extensive use of robotics, computer controls, advanced sensors and microprocessors. In fact, General Motors has the largest R&D budget of any firm in America. Machine tools, an old, 19th century industry, has been completely transformed by joining the tools to digital computers. A numerically controlled machine tool has a completely different set of economic potentials from a machine tool requiring a human operator.

Agriculture is usually regarded as the prototypical traditional industry. Yet American agriculture has long been a high technology industry in the sense of making extensive use of scientific personnel and scientific methods. American agriculture makes great use of sophisticated scientific techniques, such as genetic engineering, to develop products with highly desirable characteristics, such as disease resistance, shorter growing seasons, fertilizer responsiveness. Geneticists have developed tomatoes that ripen simultaneously and have thick skins, so that they can be picked by machines (Scientists are now hard at work trying to make these new tomatoes taste like tomatoes!).

The clothing industry, another prototypical "traditional" industry, is currently absorbing a number of innovations from a range of high technology sources. For several decades now the chemical industry has been developing an expanding range of synthetic fibers with all sorts of desirable characteristics, such as wrinkle resistance, crease retention, etc. Synthetic fibers are now a more important input into the clothing industry, in dollar terms, than natural fibers. In addition, the clothing industry is absorbing a number of innovations from electronics and laser technology. CAD/CAM is being increasingly utilized in both the high fashion and mass produced sectors of the clothing industry. Lasers, a highly sophisticated technology, are increasingly being used to cut the cloth into its appropriate shapes. In addition, the laser is finding a wide range of applications all over the industrial map in both high technology and low technology sectors. It is widely used in shaping and joining metals, but it also performs extremely delicate forms of surgery, high quality reproduction of sound, new and more precise techniques of measurement, high quality printing, a new and more efficient form of transmission, with optical fibers, in telecommunications, etc.

Thus, high technology is pervasive and affects economic efficiency in all sectors of the economy--in the same sense that an industry that was high technology at the turn of the 20th century, electricity, is now utilized in all sectors of the economy. I think it is a fair statement that future economic efficiency and competitiveness will turn, to an increasing degree, upon the ability to incorporate high technology inputs.

The speed and the extent to which these new technologies are being incorporated throughout the industrial system calls into serious question the practice of thinking of an "industry" as if it were a reliable unit of economic analysis that was subject to a reasonably stable and unambiguous definition. To an increasing degree, industries have less clear and less well-defined boundary lines. This is dramatically apparent in the blurring of the clear boundary line that could once be drawn between the telephone and computer industries. The microchip revolution and the growing information processing needs of business are converting computers into forms that increasingly resemble telecommunications networks, while the old telephone system has already become, in a very meaningful sense, a gigantic computer. A "busy" signal once meant, unambiguously, that two people were engaged in conversation - or, just possibly, that a phone was left off the hook. Today it may also mean an electronic linkup, via a modem, to a central computer. Furthermore, telephone switching systems are now being converted to a fully electronic technology, after having begun manually and after using an electro-mechanical mode for several decades. Within the office context, the electronic work station is, in fact, a specific merger of the telephone and the computer. The recent changes in the composition of the output of AT&T and IBM, and the mutual contesting of one another's traditional markets, is a specific reflection of the rapid blurring of once well-established industry boundary lines.[1/]

There is another dimension to the transfer of high technology that is of critical importance: the rapid transfer of high technologies across international boundary lines. New technologies are moving away from their country of origin more rapidly than in the past. A major reason for this is

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[1/] Of course, AT&T's recent movement into new product markets is also a consequence of the 1982 divestiture decision in the federal courts.

the impact of some of the very same high technologies with which this paper is concerned. Modern techniques of transportation and communication - the jet aircraft, telecommunications, the computer - guarantee that, whoever may be the technological leader, other countries will soon be provided access to those technologies. And, of course, the growing role of the multinational firm plays a particularly important role in bringing this about. American multinational firms are not only conducting more of their manufacturing operations abroad; for a variety of reasons, including relative costs and the nature of government regulations (e.g., in pharmaceuticals) an increasing proportion of R&D activity is being conducted abroad.[1/]

Thus, an extremely important aspect of global high technology competition is that leadership and advantages in any technology will be retained for shorter time periods than before. Technological leaders will have to deal with the hard fact that their control over a new product will last only briefly, and that a number of countries with other economic advantages, such as access to cheaper labor, will soon be taking over larger

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[1/] "U. S.-based multinational firms are transferring their technology to their foreign subsidiaries much more quickly than in the past. One study of technology diffusion found that in 1969 to 1978 about 75 percent of the technologies that were transferred to subsidiaries in developed countries were less than 5 years old; in 1960 to 1968, the proportion was about 27 percent..." Edwin Mansfield, "Microeconomics of Technological Innovation." in Ralph Landau and Nathan Rosenberg (eds.), The Positive Sum Strategy, National Academy Press, Washington, D.C., 1986, p. 320.

and larger portions of their markets.

There is an additional and very different reason why control over any new product is likely to last for shorter periods of time. Not only do less advanced countries acquire the necessary capabilities more quickly; in addition, the very speed of technological change in the advanced economies is having the same effect. Precisely because technological change is becoming so rapid in some high technology sectors, new products are rapidly being rendered obsolete by even newer products, products of lower costs or superior performance characteristics, or both. Thus, not only are a number of countries acquiring the capability to compete in existing markets more rapidly; in addition, the very speed of technological change in the most advanced countries is bringing about shorter product lives for their own products.

II.

This shortening of product lives for the technological leaders poses some critical problems. Because, while they must look forward to shorter time periods during which they can hope to recoup the costs of new product development, the financial resources that need to be devoted to the development of the new product, or its appropriate manufacturing technology, are increasing. This growing squeeze, created by shortening product lives on the one hand and rising development costs on the other, is likely to remain one of the basic facts of economic life in high technology industries.

I would like to illustrate the role of rising development costs by looking briefly at what is admittedly an extreme case: the commercial aircraft industry. Although it is an extreme case, it usefully exemplifies some trends that are at work elsewhere. Furthermore, it illustrates certain kinds of high technology opportunities that are already becoming available to newly-industrializing countries. Brazil, for example, now has a considerable aircraft industry. Other NICs are already participating in the industry in more modest ways.

For some years, the commercial aircraft industry in America was able to limit development costs by adopting new technologies only after they had been produced and operated for some years in the military. The Boeing 707 was a civilian version of the KC-135 military tanker, an aircraft that had been produced in large numbers for the military, and even the 747 had had the considerable benefit of the development experience that Boeing derived from its unsuccessful bid in the C-5A competition. With the increased focus upon the missile in the 1950s, however, the military and commercial sectors have diverged, and firms in the commercial aircraft sector now confront costs of the order of a couple billion dollars in the development of a new generation of widebodied jets and jet engines. By comparison, the development costs of the spectacularly successful DC-3 back in the 1930s were slightly more than 3 million dollars. In 1981, McDonnell-Douglas refused an offer by Delta Airlines to undertake the development of a new commercial aircraft, despite Delta's willingness to place an advance order of over $1.5 billion with the firm.

Thus, in the case of the commercial aircraft industry, participating firms confront extremely high costs of product development in addition to the actual costs of production. The situation is very much compounded by the fact that the market for commercial aircraft is relatively small - in part, a testimony to the high productivity of commercial jets. Few commercial jets ever sell in excess of a couple hundred units--and only 3 (the 727, the 737, and DC-9) have ever sold in excess of a cumulative total of 1,000.

Thus, the extreme commercial risks posed by high development costs are likely to dominate developments in this industry in the future. These risks are already reflected in a variety of new organizational arrangements. Subcontracting, at least partially as a risk-sharing device, is already an important aspect of the industry. Boeing had six major subcontractors for the 747, with whom it shared the development costs and risk, and it undertook the development of the aircraft only after it had firm purchase commitments in hand from Pan Am, TWA, Lufthansa and BOAC. Boeing has extensive subcontracting arrangements for its new generation 757 and 767 with a number of foreign firms--Japanese, Canadian, Italian, British.

High development costs and accompanying large size of financial risk also figure prominently in the increasing recourse to international consortia--as in the case of the European Airbus and the ill-fated Concorde. Although there are presently only 2 commercial airframe manufacturers and 2 commercial jet engine manufacturers in the U. S., the numbers are even smaller in western Europe where the industry is now largely nationalized. In addition, it is important to observe that the Concorde, a brilliant engineering achievement but a commercial disaster (only 16 were manufactured before production was discontinued) was made possible by immense subsidies from the French and British governments.

Although the size of development costs and the associated financial risks are extremely high in commercial aircraft, similar trends are apparent in other high technology industries. Development costs of nuclear power reactors, where safety and environmental considerations are especially important, have moved inexorably upwards. But even more conventional power generating equipment, though not plagued by the special problems of nuclear power, also confronts technological and other performance uncertainties of a kind that have resulted in very high development costs. Telecommunications also encounters very high development costs--the cost of the #4 Electronic Switching System at AT&T was around $400 million. Entry costs into biotechnology today on a scale that takes advantage of the economies of bulk manufacture are very high--in most cases too high to attract venture capital into the segment of the industry where production occurs. Although the electronics industry has some very different features from the industries just mentioned, the design and development of reliable, high-capacity memory chips has drastically raised the stakes for commercial survival. Hundreds of millions of dollars of development costs have been incurred in the international competition for increased circuit densities. In computers, IBM has an annual R&D budget these days of about $2.6 billion. It is reported to have spent $5 billion in developing the 360 computer. The average cost of bringing a new drug to market 20 years ago was $1.3 million and took about 2 years. More recently the average cost has been about $50 million and elapsed time about 8 years.

As a result of rising development costs in high technology industries, it is reasonable to expect to see a variety of joint arrangements among companies and among countries in the years ahead. The aircraft industry is an interesting one partly because these arrangements have already emerged there--Airbus Industrie in Europe, joint ventures among firms from different countries (G.E. and France--SNECMA), elaborate subcontracting and risk-sharing arrangements between Boeing and several Japanese aircraft manufacturers, joint development arrangements between a group of Japanese jet engine manufacturers and British Rolls-Royce, a newly-emerging consortium for developing a new engine for a 150 passenger plane that includes Japanese, American, German, French and English participants, etc. The pressure of rising development costs is likely to introduce similar arrangements in other high technoogy industries--as it already has in the launching and operation of European commercial satellites (Ariane).

International joint ventures pose a number of very interesting problems. Individual countries obviously enter into these arrangements, not only with different capabilities, but with different long-term goals as well. In aircraft, the Japanese, for example, clearly hope eventually to attain commercial superiority over other participants, and probably regard such joint ventures as vehicles for the attainment of certain skills (e.g., design capabilities) that they do not presently possess.

While these international joint ventures offer great potential advantages to the participants (sharing of development costs, more favored treatment in gaining access to specific markets, new complementary capabilities, etc.) they also contain certain elements of inherent instabilty.

Thus, industries confronting a combination of a dynamic, rapidly improving technology and high levels of development costs may be expected to share, in varying degrees, a range of common problems. Financial risks are becoming exceedingly great, in some cases requiring markets substantially larger than can even be provided by a single moderately-sized western European country of 50 million people or so.

For technological and other reasons (sometimes regulatory), long lead times are often involved that postpone the prospect of full recovery of financial commitments, at best, into the far distant future. Not only are uncertainties over technological factors particularly great, but the large financial commitments are frequently required during precisely those early stages when uncertainties are greatest. The very fact of rapid technological change raises the risk of investing in long-lived plant and equipment, since further technological change is likely to render such capital soon obsolete. As product life cycles are themselves becoming shorter, the agony of the risk-taking process is further intensified. The question of timing in the commitment of large amounts of resources to the development process becomes even more crucial. There is abundant evidence in recent years that new, technologically-complex products experience numerous difficulties in their early stages that may take years to iron out. The earliest innovators frequently wind up in the bankruptcy courts. The strategy of a rapid imitator, of "fast second," benefiting from the mistakes of the pioneer, has much to commend it especially, of course, when technological change is expected to continue to be rapid. This was clearly the case with British pioneering of the first commercial jet, Comet I, well before American entry into the commercial jet age. As it happened, substantial improvements in engine performance in the next couple of years offered Boeing and Douglas decisive commercial advantages, in terms of greater capacity and speed, that were incorporated into their later entrants--the 707 and DC-8. The British, who are usually criticized for being too slow to innovate, clearly suffered in the commercial aircraft industry in the 1950s because they innovated _too rapidly_. Again, timing is crucial.

This problem is, if anything, even more serious in electronics where the technology is changing very rapidly and where it is confidently expected by all parties that it will continue to change rapidly. Under these circumstances, the decision to commit resources to large-scale investment in manufacturing equipment is extraordinarily difficult. Since potential purchasers of electronics products _also_ expect rapid technological change to continue, it takes a great deal of effort, or very low prices, to persuade them of the wisdom of buying now rather than later.

III.

Competition in international markets for products of the high technology industries has intensified in recent years as a result of reduced transportation costs and the increasing prominence of industries in which such costs are relatively unimportant, such as electronics. An important outcome, to which I would like to call attention, has been entirely new patterns of the international division of labor. It is now feasible for a firm to parcel out separate activities or components on a truly international basis, as a result of which it becomes increasingly difficult to pin a national label on a particular product. Thus, buyers of Boeing's 767 are purchasing an aircraft the components of which have been manufactured in several countries on different continents (The fuselage is made by shipping rolled aluminum from Pittsburgh to Osaka. The completed fuselage is then shipped to Seattle.) Boeing will happily deliver the aircraft equipped with American engines (Pratt and Whitney or General Electric) or British engines (Rolls-Royce) to suit the preferences of the buyer. The European Airbus, on the other hand, comes equipped with American engines (General Electric). In fact, Airbus products are about 30% American in content. The smaller commercial aircraft now being manufactured in Brazil include American components that may constitute as much as 40% of the value of the final product.

The present situation in the computer industry is equally fluid. Superficially, it appears that American industry dominates the world market, especially the mainframe market, with about 80% of total sales. However, on closer inspection, the situation is much more complex. Most memory chips are produced by the Japanese. Many American computer terminals are made in Korea. Although Japanese manufacturers have not made major inroads in the sale of personal computers in the U. S. market, over 80% of the U. S. market for personal computer printers in 1984 were in fact Japanese. (Epson had the largest share of the U. S. PC printer market--with 30% of the total. Moreover, almost <u>all</u> the low-cost dot matrix printers sold in the U. S. are made in Japan.) In addition, disk drives are mostly Japanese.

Similarly, if we look at a single product, such as IBM's highly successful PC, the picture is much more complicated than might appear at first glance. All parts of the PC are multi-sourced. The IBM PC employs Intel processors that were sourced from Hitachi, it employs a TDK power supply and Epson printer (all from Japan), and it is equipped with an Atlas monitor that comes from Hong Kong.

On the other hand, American producers continue to be strong not only in mainframes but in those portions of the computer market that are software-intensive. In semiconductors, whereas Japan now dominates the memory chip market, the U. S. remains very strong in the high quality end of custom chips and microprocessors.

The purpose of these observations is not to suggest that the boundary lines between American and Japanese strengths will continue to remain drawn along their present lines. That would be fool-hardy! Rather, it is to suggest the possibility of entirely new patterns of specialization at the common technological frontier, as the participants at that frontier become more numerous--as they will. These new patterns are of such a nature that it makes little sense to apply terms such as "technological leadership" or "technological gaps" to entire industries, much less entire countries. It is also possible that countries that are generally regarded as far from the technological frontier and at intermediate stages of industrialization--India, Korea, Brazil, Mexico--may establish niches for themselves in certain portions of high technology industries. Under this new international division of labor, countries specialize, not in entire products, but in separate components of high technology products. Korean shipbuilding once operated by importing Japanese marine engines and complex navigational components in the same way as Brazilians currently manufacture aircraft with American engines and components. To an increasing extent, complex products are being sold in world markets by manufacturers who purchased separate components from suppliers in a number of different countries. This is already true of Boeing. Boeing, in manufacturing aircraft, has an international network of suppliers and is becoming increasingly a prime contractor for components made all over the world (fuselage of 767). In fact, even the term "manufacturer" is becoming less applicable to Boeing. Boeing's activities are, more and more, that of a designer of aircraft and an assembler of components made elsewhere, often overseas. IBM is coming to occupy a similar role, as a designer and assembler of computers.

From the point of view of the newly-industrializing countries, the number of doors through which they can enter high-technology markets is increasing. They can assemble components made elsewhere or they may become suppliers of specific components to overseas assemblers. Either way, the world-wide division of labor in these industries is changing. And these changes will, without doubt, continue.

IV.

One of the big uncertainties for the future is the extent to which technological changes will alter some of the current trends that I have been examining, especially the rise in development costs.

For example, technological change may come to the rescue in limiting the trend toward rising development costs in high technology industries. Specifically, further progress in computer technology may make it possible to achieve drastic cost reductions in the development process. CAD/CAM techniques may make it possible to move directly from the design of a new product to the most efficient methods of manufacturing. They may make it possible to infer the most efficient methods of manufacturing a new product directly from data about the design itself. This could speed up the introduction of the process technologies to which new product innovations give rise. Indeed, this is already happening.

> For machining, this integration is reflected in the automatic output of numerical control programmes; in electronic components by the automatic generation of production 'masks'; in casting (of metals) by the automatic design of moulds; and for the future, in assembly by the automatic production of robot programs to assemble complex components.[1/]

CAD/CAM may not only reduce development costs, but also speed up the process of development and setup time for manufacturing. It may also make possible the achievement of products of better design characteristics.

Furthermore, the computer and the microprocessor are bringing automation into the research process itself (The R of R&D). In pharmaceuticals, automation already makes it possible to monitor toxicological tests on large populations of animals. In this way, testing procedures can be conducted more quickly and the time that elapses before certain new drugs can be brought to market has been drastically reduced.

Somewhat farther down the road, large computers may replace all sorts of time-consuming and expensive experimental procedures. For example, large computers may replace wind tunnels for experimentation with new aircraft designs, and they will also facilitate the search for valuable new chemical

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1/ OECD, Software: A New Industry, pp. 122-3.

compounds. Large supercomputers were used to design the wings of both the Boeing 767 and the European Airbus 310. New airfoil designs can be, in effect, 'flown' on a supercomputer, then modified, and subsequently 'flown' again--all on the computer--until optimal performance and design are achieved. Computer simulation techniques are now being used "to simulate systems whose complexity approaches that of the real world." Such techniques are already being applied in elementary particle theory, in astrophysics, in automobile design, in the exploitation of oil reservoirs, in dealing with the behavior of metals under stress, and many other fields.[1/]

Again, the commercial aircraft industry is interesting because CAD/CAM has been playing an important role there for a number of years. CAD has made it possible to design parts with a far higher degree of accuracy and speed than was attainable before. The computer plays a major role in inventory control, scheduling requirements, and the very rapid custom building of replacement parts. The Boeing 757 and 767 would have cost far more to design and build without CAD/CAM techniques.

In addition, CAE is speeding up the process of product design in a number of industries. In electronics and elsewhere, CAE permits engineers to bypass the old method of actually building a physical prototype. CAE, in effect, makes it possible to use the computer to test and to evaluate the performance of a prototype that has been designed but not yet built.

The ultimate effect of these new computer-based technologies is not clear. While they will certainly offer the possibility of reducing

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[1/] Science, 3 May 1985, p. 568.

development costs, the competitive process may drive in the direction of reducing product life cycles even further. If that were to happen, it would not bring much financial relief to high technology industries. On the other hand, CAD/CAM/CAE may also provide an effective bridge between product cycles. This bridge may make it possible for successive product cycles to use essentially the same design, manufacturing and engineering equipment. Such a development would provide some financial relief for the firm as well as the prospect of cost reductions to the consuming public.

In the context of the changing international division of labor, some of the newly-emerging technologies may have other surprising effects. For a number of years, the labor-intensive stages of high technology industries have moved offshore from the U. S. and Japan to the NICs where labor is a good deal cheaper. Some of the new technologies may reverse that flow. It is entirely possible that new forms of automation, robotics and flexible manufacturing systems may drastically reduce labor requirements. If that were to happen, manufacturing activities that have recently moved to southeast Asia or northern Mexico may return to the U. S. and Japan. These new "labor-saving" technologies would thus have clearly employment-increasing effects in the industrial eocnomies.

V.

The conditions that I have examined so far in this paper have important implications for U. S. competitiveness in high technology markets. The advantages that have accrued in the past from control over more advanced technologies have been eroded by circumstances that make these technologies more rapidly available to potential competitors. The rise in development costs associated with these new technologies has not only reduced the economic benefits brought about by such control; it is also leading to the search for overseas partners in joint venture arrangements. While these joint ventures do indeed offer the prospect of a sharing of high development costs as well as other benefits, they also assure the even more rapid diffusion of the new technologies.

The faster international transfer of new technologies is also undercutting what was once a major source of American superiority in high technology markets: its large, first-rate scientific research capability that sometimes generated economic advantages in new technological developments that flowed from scientific leadership. I feel compelled to say that, in my view, Americans (and especially members of the scientific community) have exaggerated the purely economic benefits that flowed from leadership at the scientific frontier. This is not a denial that great economic benefits flow from the conduct of scientific research - rather it is a denial that these benefits necessarily flow in the form of competitive economic advantages to the country conducting such research. Great Britain's experience in the post-war years convincingly demonstrates the insufficiency of high quality science when it is not associated with the complementary managerial and engineering skills, and when the economic environment is one that does not offer a sufficient prospect of high rewards to technological innovation or to the adoption of newly-available technologies. On the other hand, the experience of Japan has forcefully demonstrated the remarkable possibilities for economic growth based upon the systematic transfer and exploitation of foreign technologies. Given the appropriate managerial, engineering and organizational skills - admittedly a large "given" - and so long as more advanced technologies are available from abroad, rapid economic growth is possible. To a far greater degree than we once believed, a first-rate, domestic scientific research capability is neither sufficient nor even necessary for economic growth. This should not be terribly surprising. The fruits of scientific research have always been highly portable; events of recent decades are rendering the findings of technological innovation highly portable internationally as well - at least under the right set of arrangements in the recipient countries. By the right set of circumstances I mean the set of capabilities associated with the commercialization of new products or processes - the skills tha reside at the "downstream" end of the spectrum of activities that make up R&D, as well as a macroeconomic environment where high rates of savings and low interest rates create an environment highly conducive to investment activity and long time horizons in industry.

Japanese economic performance over the past 30 years supports these assertions. The Japanese have, on numerous occasions, been the leaders in the commercialization of new products, in spite of the fact that the new product, or some essential component, was invented elsewhere. Thus, although the U. S. pioneered at both the scientific and technological levels in the sequence of events that led to the invention of the transistor and integrated circuit, Japan was the first country to succeed in the large-scale commercialization of transistor technology for radio and she simply obliterated America's earlier dominance of color television. Similarly, in robotics, where past American leadership was conspicuous, Japan by 1982 was actually employing more than 3 times as many robots as the U. S. More recently, the video cassette recorder was an American conception and invention, but its successful commercialization has been entirely a Japanese affair. Indeed, it is one of Japan's largest export items, recently generating almost $6 billion per year in export earnings.

To discuss the conditions that would make for successful commercialization would require at least a separate paper. I will have to be content with a few observations. The virtues of originality, creativity and innovation are deeply rooted and exhuberantly celebrated in American culture - as they should be. Associated with this celebration, however, is an impatience and neglect and lower esteem for working out the finer details of product design or the organization and flow of work on the factory floor. From a commercial point of view, however, these "mere" details translate into performance and cost differentials that are often decisive for success or failure in the market place. One measure of the greater priority and systematic nature of the Japanese approach to these downstream development activities is a recent finding that the Japanese have a product development cycle that is a great deal shorter than the American one - perhaps as much as 50% shorter.[1/]

[1/] Ken-Ichi Imai, Ikujiro Nonaka, and Hirotaka Takeuchi, "Managing the New Product Development Process: How Japanese Companies Learn and Unlearn," Chapter 8 in Kim Clark et al. (eds.), The Uneasy Alliance: Managing the Productivity-Technology Dilemma, Harvard Business School Press, Boston, 1985.

It is still more common than it should be to characterize the Japanese as mere imitators or borrowers, in spite of the fact that, at the technological level, they have already attained positions of leadership, or near leadership, in a number of fields: fiber optics, composite materials, fermentation processes, computer peripherals, memory chips, numerically-controlled devices. In fact, an examination of Japanese R&D spending activities is very illuminating. The Japanese have had a highly R&D-intensive economy for a long time. Although the American share of GNP has been considerably higher than the Japanese until very recently, that differential has been entirely accounted for by the very large share of U. S. R&D that is devoted to military purposes. If one compares civilian R&D expenditures in the two countries, it appears that the Japanese share has exceeded that of the U. S. for at least a quarter of a century.[1/] Furthermore, the share of R&D that is privately financed is higher in Japan than in the U. S. or other industrial countries.[2/] This suggests strongly that Japanese success in high technology industries has been heavily built upon providing appropriate incentives to private industry, rather than (as is often complained) heavily government-subsidized programs.

[1/] Science Indicators.

[2/] This remains true even when the comparison is restricted to non-defence expenditures. See Dan Okimoto, "The Japanese Challenge in High Technology," in Ralph Landau and Nathan Rosenberg (eds.), The Positive Sum Strategy, op. cit., p. 551.

Finally, Japanese R&D has been heavily concentrated in applied directions, although the basic research component has become more prominent in recent years. It has also had a strong focus upon monitoring and assessing R&D activities throughout the industrial world. I suspect that devoting more resources to finding out what is going on outside the U. S. is one of several ways in which we might benefit from imitating the Japanese.

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