Title

Beating Our Plowshares into Double-Edged Swords: The Impact of Pentagon Policies on the Commercialization of Advanced Technologies

Author
Stowsky, Jay

Publication Date
1986-04-03

Beating Our Plowshares into Double-Edged Swords: The Impact of Pentagon Policies on the Commercialization of Advanced Technologies

Jay Stowsky

Working Paper 17
April 1986

CONTENTS

I. Introduction 1
A. The Problem 1
B. The Defense-Economy Debate 2
C. Underlying Questions 5
D. Overview 7

II. Both Sides of the Story: Programs Past 10
A. Semiconductors 10
B. Numerical Control 17

III. The Pentagon and the Firm 25
A. Two Strategies 25
B. Firm Governance Structure 27
C. One Step Forward, Two Steps Back 32
D. Volume Production Strategies: the Role of Military Procurement 33
1. Protection 33
2. Sole-Sourcing and Cost-Plus Contracts 34
3. Production Volume 36
E. Production Innovation Strategies: Advancing the State of the Art 37
1. Price Premiums 38
2. Technological Over-Sophistication 38
3. Direct Subsidies for R&D 40
4. Applied R&D 40
5. Over-Specialized Personnel 41
6. Diffusion 43
7. Restrictions on Diffusion 44
F. Summary 46

IV. The Story in Progress: Current Programs 48
A. VHSIC 48
B. The Strategic Computing Initiative 54

V. Conclusions and Concerns 60

Jay Stowsky is a research affiliate with the Berkeley Roundtable on the International Economy (BRIE) and a doctoral candidate in the Department of City and Regional Planning at the University of California, Berkeley. He holds a Master's Degree in Public Policy from the John F. Kennedy School of Government at Harvard University and an A.B. in the Political Economy of Industrial Societies, also from U.C. Berkeley. Mr. Stowsky has recently authored studies on the effects of trade and technological change on employment in the U.S. semiconductor and telecommunications equipment industries.

I. Introduction

The Problem. The defense of U.S. interests--both militarily and commercially in world markets--depends ever more powerfully on the breadth of America's technological edge. That advantage depends, in turn, on the nation's ability to generate and commercialize technological innovation. With more than a third of the nation's $107 billion investment in research and development now going to defense-related programs--including between 70 and 80 percent of the funding for research into such cutting-edge technologies as lasers, artificial intelligence, and advanced materials--that capacity, and thus the economic as well as military prowess it can promote, depends ever more directly on the technological priorities of the U.S. Department of Defense.[1]

Pentagon involvement in U.S. industrial development is nothing new. Yet not since the 1950's have the resources for public support of advanced technological research been so concentrated in the hands of military officials. More than 70 percent of all federally-funded R&D is now linked to military programs, up from about 50 percent in the late 1970's.[2] The Pentagon has pumped billions into the development of fuel-efficient jumbo jet engines, superspeed computers, high-density semiconductors, vision-equipped robots, and computer-aided manufacturing systems. But this is only the beginning. Already, Pentagon strategists have enticed Congress with the potential commercial benefits of major military research initiatives in microelectronics and supercomputing. Soon, they propose to spend nearly $100 million per year to bolster the nation's leading research universities.[3] And recently, the Defense Department set up a new office for identifying and financing high-risk proposals from innovative high-tech entrepreneurs. Budgeted at $1.3 billion for its first four years, this office will

---

1. National Science Foundation (NSF Report 84-311) National Patterns of Science and Technology Resources, 1984; Robert B. Reich, "High Tech, a Subsidiary of Pentagon, Inc." New York Times, May 29, 1985, page 27; W.C. Boesman, "U.S. Civilian and Defense Research and Development Funding," Science Policy Research Division, Congressional Research Service, August 23, 1983.
2. NSF Report 84-311, op. cit., and National Science Foundation (NSF Report 84-333) Science Resources Studies Highlights, "Defense Research and Development Emphasized in 1985 Budget," (Washington, D.C.: NSF, November 30, 1984).
3. Colin Norman, "DOD Program Proves Attractive," Science, Volume 228, Number 4705, June 14, 1985, page 1291.

account for roughly one-fifth of the nation's high technology venture capital.4

Most enticing of all, perhaps, are the potential commercial benefits of the Reagan Administration's Strategic Defense Initiative (SDI), better known as "Star Wars." Budgeted at $1.4 billion for 1985, projected to cost roughly $26 billion over the next five years, SDI actually represents only a small fraction of the nation's total research budget.5 But that fraction encompasses the farthest reaches of today's technological frontier. Public debate over the President's initiative has focused almost exclusively on the project's technical and strategic feasibility, but the attempt itself aims at more technological breakthroughs, involving more scientists and engineers, than either the Apollo space program or the development of the atomic bomb.6

Still, American policymakers would be well advised to take a closer look at the longer-term commercial implications of current defense policies. For, just as the Pentagon is contracting with American manufacturers to pursue the technological breakthroughs necessary to produce such exotic armaments as stealth bombers and laser-beam defense shields, other nations' manufacturers are aggressively pursuing the same breakthroughs with commercial applications specifically in mind. Indeed, Europe's huge, commercially-oriented Eureka project grew directly out of French President Mitterand's fears that European firms would otherwise be distracted--or prevented--from engaging in commercial development of the technologies underlying SDI or forced into integrated production controlled by the U.S.

The dilemma, in brief, is this: America's defense needs do not necessarily complement its prerequisites for competitive industrial development. By pursuing both goals at the same time, the United States is failing to make explicit the significant trade-offs involved when the exigencies of national security interfere with the requirements for successful economic competition. And as a result, the United States is in danger of ceding to its economic rivals what it is apparently determined to deny its military rivals at almost any cost--permanent competitive advantage across a variety of contested fronts.

<u>The Defense-Economy Debate</u>. A debate has raged in the U.S. since before World War II about the impact of defense

4. Robert B. Reich, <u>New York Times</u>, May 29, 1985, <u>op. cit</u>.
5. <u>ibid</u>. and NSF Report 84-333, <u>op. cit</u>.
6. <u>ibid</u>.

spending on the civilian economy.[7] It was Keynes who wrote, at the beginning of that conflict, that "War preparations, so far from requiring a sacrifice, will be a stimulus unto greater individual consumption and a higher standard of life."[8] It was not until after the war had proven his point, however, that Lord Keynes' ideas filtered into the economic mainstream. Once they did, `military Keynesianism' was widely held to be a crucial factor behind America's economic prosperity in the 1950's and 60's. Variants of this view were expressed by economists with such diverse political inclinations as Paul Baran and Paul Sweezy, John Kenneth Galbraith, Arthur Burns, and Murray Weidenbaum.[9] Today, prominent analysts continue to hypothesize a link between American competitiveness in high tech sectors and the massive defense budget for research, development, and procurement in those areas. "It is probably no accident," wrote Charles L. Schultze in 1982, "that Japanese competitiveness and exports are particularly strong in consumer goods while the United States is a strong world competitor in fields more closely related to defense, such

7. For a good summary discussion, see John Tirman, "The Defense-Economy Debate," in John Tirman, ed., The Militarization of High Technology (Cambridge, MA.: Ballinger, 1984). Chapter 1, pages 1-32.

8. John Maynard Keynes, The New Republic, Volume 103, Number 5, July 29, 1940, page 158.

9. Paul Baran and Paul Sweezy, Monopoly Capital: An Essay on the American Economic and Social Order (New York: Monthly Review Press, 1966); John Kenneth Galbraith, The New Industrial State (Boston: Houghton Mifflin, 1967); Murray Weidenbaum, later chairman of President Reagan's Council of Economic Advisors, found that, ever since the Spanish American War, a sharp rise in the stock market has been associated with each period of military conflict. See Murray Weidenbaum, The Economics of Peace-Time Defense (New York, Basic Books, 1974); Arthur F. Burns, chairman of President Eisenhower's Council of Economic Advisors and chairman of the Federal Reserve Board during the Nixon and Ford Administrations, has noted the utility of defense spending as a countercyclical measure. See, for example, The Defense Sector and the American Economy, The Moskowitz Lectures, Number VIII (New York: New York University Press, 1968), reprinted in Seymour Melman, ed., The War Economy of the United States (New York: St. Martin's Press, 1971) pages 111-121.

as aircraft, computers, large-scale communications and the like."10

Confidence in the beneficence of military spending for industrial competitiveness was buttressed in the mid-1960's by a set of sectoral technology studies by the OECD, titled Gaps in Technology. The OECD studies detailed how U.S. military spending had pushed the pace of innovation and widened the U.S. technological edge in a range of industries including aircraft, computers, and microelectronics. Indeed, much of today's European irritation over U.S. export controls on dual-use technologies (technologies with both military and commercial applications) springs from the perception engendered by those studies. There is a widespread belief among America's principal trading partners that access to crucial commercial technologies has been denied to them for reasons that have little to do with American security. To them, it appears that the United States is running an industrial policy through the Pentagon as a convenient pretext for protecting its share of world markets (even while American politicians continue to engage in the rhetoric of free trade).11

As indicated by the OECD studies, the association between Pentagon involvement and commercial success appears to have been quite strong in some high tech sectors in earlier years (setting aside for the moment any suggestion of a causal connection). It is somewhat surprising, then, that American firms have experienced some of their most dramatic recent losses of world market share in precisely those industries which traditionally have been most closely tied to the Department of Defense--aircraft, electronics, and machine tools. It is this empirical observation, so at odds with dominant perceptions regarding the beneficence of Pentagon involvement in market-oriented high tech sectors, that has led many observers to re-examine the link between military programs and industrial competitiveness.

Indeed, during the 1970's and early 1980's, an alternative perspective emerged which challenged the conventional belief that military spending promotes economic growth and industrial competitiveness. An equally

---

10. cited in Michael R. Gordon, "Will the Pentagon's Ad Hoc 'Industrial Policy' Ultimately Hamper U.S. Industrial Creativity" in High Technology: Public Policies for the 1980's, a National Journal issues book, (Washington, D.C.: National Journal, 1983). Schultze was Chairman of the Council of Economic Advisors during the Carter Administration; the quote is from an article he wrote for the January-February 1982 issue of Challenge.
11. Michael Borrus and John Zysman, "Alliances, Networks, and International Competition," Datamation, Volume 31, Number 11, June 1, 1985; pages 187-191.

politically diverse set of commentators, including Seymour Melman, Mary Kaldor, James Fallows, Lester Thurow, and George W.S. Kuhn highlighted the growing tension between increasingly specialized military technology applications and the more standard, cost-efficient commercial applications required by civilian producers and consumers.12 Their arguments suggested, in fact, that massive defense spending did great harm to the economy--particularly its key technology sectors--by creating bottlenecks in production, encouraging cost-inefficiency, and diverting human and capital resources away from commercial priorities toward high-cost, low-volume, over-sophisticated military applications.

Underlying Questions. The debate continues, but despite their differences over the competitive implications of massive military spending, the commentators cited above all agree that major defense projects powerfully affect the aggregate performance of the civilian economy. Our own review convinces us that major military programs can also significantly influence the competitive position of U.S. producers. That influence derives primarily from the impact of military programs on the trajectory of technological development. It is our contention, however, that whether that influence is positive or negative depends on the case-by-case answers to several underlying questions:13

1. Is the military program designed to advance the technological state-of-the-art or is it aimed at the development of specific military product applications?

---

12. See, for example, Seymour Melman, The Permanent War Economy: American Capitalism in Decline (New York: Touchstone/Simon and Schuster, 1974). Melman's other works include Our Depleted Society (1965), Pentagon Capitalism (1970), and Profits Without Production (1983). He has also edited several influential collections, including Conversion of Industry from a Military to a Civilian Economy (1970) and The War Economy of the United States (1971). On the subject of technical overdevelopment in the military, see Mary Kaldor, The Baroque Arsenal (New York: Hill and Wang, 1981) and James Fallows' highly influential National Defense (New York: Vintage, 1982); for a liberal economist's view, see Lester Thurow, "How to Wreck the Economy," The New York Review of Books, May 14, 1981; for a conservative critique which agrees substantially with the views expressed by Kaldor, Fallows, and Thurow, refer to George W.S. Kuhn, "Department of Defense: Ending Defense Stagnation," in Richard N. Holwill, ed., Agenda '83 (Washington, D.C.: Heritage Foundation, 1983) pages 69-70.

13. These questions are the product of several exchanges with Michael Borrus and John Zysman.

2. If military product development is the main objective, how far do the military specifications diverge from the commercial market requirements of the involved industry?

3. Is the military program designed to encourage competitive product development and efficient, generalizable production technologies, or does it encourage reliance on sole-source suppliers and cost-plus, weapons-specific production technologies?

4. Does the military program respond to demand that is stable or growing at a predictable rate--thus making economical mass production by dedicated assembly-line techniques--or is the demand, instead, for "off-line" items, goods or systems for which substantial stable demand never exists, and which must be manufactured, therefore, in small batches using highly specialized and expensive production equipment that commercial manufacturers cannot afford on their own?

5. At what stage of the life-cycle is the involved industry's development? Does it have an established set of commercial priorities, backed up by large sunk investments, or has its direction of commercial development not yet been defined and confirmed by a pattern of investments?

6. Which commercial firms in the involved industry participate in the military program, and what is their competitive position within the industry? How will it change as a result of their participation in the program?

7. Will relevant military-sponsored advances be permitted to diffuse into commercial applications, and will potential industrial allies (particularly those abroad) be permitted access to the technologies?

8. Does there exist for foreign competitors a parallel, commercially-oriented R&D project explicitly aimed at advancing the commercial state-of-the-art over the same

time span as the military program, and what is the likelihood that it will succeed?

Overview. By constructing these eight questions into an analytical lens--a many-sided prism, really--through which to examine the commercial impacts of various military programs, we can begin to discover some useful patterns. In the case of early Pentagon involvement in areas such as aircraft and microelectronics, for example--two of the sectors included in the influential OECD report--military programs aimed explicitly at advancing the technological state-of-the-art, encouraged competitive product development and efficient, generalizable production technologies, provided outlets for stable volume production that enabled manufacturers to realize learning economies and large economies of scale over long production runs, occurred at an early stage in each industry's development (before the direction of commercial development had been defined and confirmed by investment), and permitted relevant military advances to diffuse into commercial applications. In both of these cases, the Pentagon clearly assisted in the creation of a beneficial and competitive trajectory of development for the affected industries.

In other cases, for example the case of numerically-controlled machine tools, the opposite has been true. In these cases, defense programs have focused on the development of specific military product applications, relied on sole-source suppliers and cost-plus contracts, underwritten the use of expensive, specialized production equipment for the manufacture of unique items in small batches, involved industries whose commercial priorities were already well-established and confirmed by a pattern of investments, and did not permit dual-use technologies to diffuse into the commercial sector. In these cases, the Pentagon has clearly inhibited the development of beneficial spinoffs and has contributed to the evolution of a militarily dependent and uncompetitive industry structure.

Our aim here is thus to begin to trace the ways in which Pentagon involvement at various stages in the development of a new technology has promoted or inhibited the commercial application and widespread diffusion of that technology. In the process, moreover, we will discover that some current programs--specifically the VHSIC program and the Strategic Computing Initiative--tend to replicate the series of actions which typically have led to a pattern of negative outcomes. This is not necessarily because these programs are poorly designed, at least from a defense perspective. Rather, it follows from the fact that military needs are no longer in the mainstream of industrial evolution in many high technology sectors. Unlike many of the programs of the 1950's and early 60's, current defense procurement policies are actually inhibiting the discovery and, especially, the diffusion of new commercial technologies. In all cases, we conclude, military procurement and R&D cannot themselves substitute for a civilian industrial policy in the face of determined, government-supported foreign efforts to advance the commercial state-of-the-art over the same time span as current U.S. military programs.

Finally, we formalize the two broad patterns produced by contrasting answers to our guiding questions with reference to an ideal competitive high tech industrial structure and a contra-ideal Pentagon procurement process. This is quite analogous, in fact, to the distinction drawn by Michael Borrus and Marcello D'Cecco between the U.S. and Soviet "military-industrial" complexes. In the U.S., as they have written,

> ...military research and development live in continuous symbiosis with civilian research and production. This has given rise to the whole conceptualization of commercially-beneficial spin-offs, by-products, and fall-outs. By contrast, in the Soviet case, the `military-industrial complex' is a clearly definable subset of the Soviet research and industrial capacities, and has very tenuous links with the civilian industry...Military industry lives a life of its own, and its relations with the civilian economy are only definable as having near absolute priority for competing claims over scarce national technical and economic resources.14

As Borrus and D'Cecco argue, the two models provide a particularly stark contrast. Nevertheless, the Pentagon procurement process approaches the Soviet model "to the precise extent that military requirements are so baroque and unguided by efficiency criteria that they in effect create a dual industry structure--one part devoted solely to serving the military, the other to civilian uses."15

For any given military program, answering the set of eight guiding questions identified in the last section permits us to determine whether the commercial impacts more

---

14. Michael Borrus and Marcello d'Cecco, "Proposal to Study the Economic Consequences of SDI," unpublished memo, Berkeley Roundtable on the International Economy (BRIE), University of California, Berkeley, 1985.
15. ibid.

nearly approximate our ideal competitive or contra-ideal Pentagon procurement models; we will employ these two models as reference points for the impacts we discover. In this fashion, we can attempt to predict where military programs are likely to produce beneficial spinoffs, and where they are likely to result in "militarily-dependent and uncompetitive industry development."[16]

16. *ibid*.

II. Both Sides of the Story: Programs Past

To begin our analysis, and to demonstrate the utility of our approach, we apply our guiding questions at the outset to two technologically advanced sectors which both experienced an intense period of military attention as soon as the innovations from which they arose were discovered at the end of World War II. As we shall see, the answers to our questions are almost uniformly friendly to a positive interpretation of the commercial implications of military programs when applied to the early development of the domestic semiconductor industry; in the case of numerically-controlled machine tools, however, the image that emerges is almost exactly the reverse. Indeed, the contrasting experiences of the two industries vis-a-vis the Pentagon clearly presage their contrasting commercial performances and help us to set the stage for an analysis of why this should be so.

Semiconductors. Like the ferociously accurate missiles it produced, the military's early relationship with the American semiconductor industry contained the seeds of its own destruction. The volume production that enabled integrated circuits to compete in the commercial marketplace with discrete components came, initially, as a result of the Apollo space program and the Pentagon's development of the Minuteman ICBM in the late 1960's; by the early 1970's, as a direct consequence, defense contractors were no longer the U.S. semiconductor industry's primary customers. Since then, moreover, the leadership position enjoyed by the U.S. industry has gradually eroded as Japanese firms have organized successfully to capture a dominant share of the burgeoning computer and industrial markets for integrated circuits. And unlike the military and space programs of the early 60's, more recent military programs have not helped--and may have hurt--the commercial competitiveness of U.S. firms.

The Bell Labs scientists who announced their invention of the transistor to the public in 1948 knew quite well that they had come up with something likely to excite the military imagination. Indeed, their announcement--like AT&T's later decisions to disclose transistor technology to the public--was motivated in large part by a concern that defense officials might try to classify or restrict the scientists' discovery. Commercial firms, on the other hand, were slow to recognize the revolutionary potential of transistor technology. According to Braun and MacDonald:

> Despite the early interest in the transistor as a better valve [tube], the transistor was so radically different from the valve in the way it worked, in the way it could be manufactured and sold, and in its apparent potential, that it could not be comfortably accommodated within the existing electronics industry without changes that that industry was then unwilling or unable to make. In its typical subjugation of semiconductor development, manufacture, and marketing within valve departments, the established electronics industry demonstrated that it was largely unaware of the impact the innovation could have.17

The early transistors were less reliable than vacuum tubes and more expensive; except for its adaptation to the manufacture of hearing aids, for which its compactness made it especially well-suited, the transistor was not regarded as an economical substitute for vacuum tubes for most consumer electronics products.

For the military, however, miniaturization of electronic circuits was a goal of paramount importance; moreover, transistors did not generate nearly as much heat in operation as did electron tubes and they were much more shock resistant. The military was willing to pay premium prices for these qualities; what is more, defense officials were willing to press for increased reliability by manufacturing equipment for the exhaustive testing of individual components and by building redundancy into its transistorized equipment almost regardless of cost.18 At the same time, military demands for miniaturization, low power consumption, and high reliability prodded the U.S. industry to concentrate on the development of silicon-based devices, a technological path different from that chosen by the Europeans and Japanese who, during the 1950's, pursued the development and mass production of germanium, transistor-based consumer electronic systems.19

---

17. Ernest Braun and Stuart MacDonald, Revolution in Miniature: The History and Impact of Semiconductor Electronics (London: Cambridge University Press, 1978) page 69.
18. William L. Baldwin, The Impact of Defense Procurement on Competition in Commercial Markets: Cases Studies of the Electronics and Helicopter Industries, U.S. Federal Trade Commission, Office of Policy Planning, December 1980.
19. Michael Borrus, James Millstein, and John Zysman, with Aton Arbisser and Daniel O'Neill, U.S.-Japanese Competition in the Semiconductor Industry: A Study in International Trade and Technological Development, Policy Papers in International Affairs #17, Institute of International Studies, University of California, Berkeley, 1982. page 15.

Most critically, the programs we are discussing were designed to encourage competitive technology development and efficient manufacture, the former because the Pentagon could not afford the risk of putting all of its technological eggs in a single basket, the latter because component technology was understood to be an intermediate input that would go into a wide variety of military and space systems.20 Both the Defense Department and the large original equipment manufacturers typically followed a strategy of "second-sourcing," requiring at least two independent sources for a component before it could be included on an approved list for use in their equipment. As described by Webbink, second-sourcing encouraged rapid technological diffusion; involved firms often shared patent rights, drawings, photomasks, and manufacturing know-how.21

As importantly, "military procurement permitted the semiconductor industry to expand more rapidly than would otherwise have been the case, accelerating an industry-wide movement down its experience curves and thus bringing its products into cost-efficient use by civilian oriented firms."22 As Tilton writes:

> The impact of military demand on the semiconductor industry transcends its size. The armed forces have always imposed the most rigid standards and quality control. They have constantly demanded better devices and have not hesitated to inform the industry of specific needs. Moreover, they provide a substantial market for new devices that meet their requirements.
>
> The latter is particularly important. Often new and better semiconductors are initially too expensive for industrial or consumer electronic products. In military equipment, reliability and performance have priority over costs, so that most new semiconductor devices first find a home in military products. As production proceeds, learning occurs and costs fall. Within a few years, the price is low enough to

---

20. Michael Borrus, BRIE memo, 1985, op. cit.
21. Douglas M. Webbink, Staff Report on the Semiconductor Industry: A survey of Structure, Conduct, and Performance, U.S. Federal Trade Commission, Bureau of Economics, January 1977, page 97. Cited in Baldwin, op. cit., pages 55-6.
22. Baldwin, op. cit. page 71.

penetrate the industrial market, and eventually the consumer market.23

In 1963, for example, the average selling price for monolithic IC's was $50; government procurement accounted for 95 percent of sales. Total IC production mushroomed during the next three years, growing from about $4 million in 1963 to roughly $80 million in 1965. By then, the government's share of sales had already fallen to 75 percent (55 percent of the total value of sales reflecting purchases by the military), while the price of IC's had plummeted to below $9 per circuit. By 1972, when the proportion of domestic IC sales to the computer and industrial markets reached 65 percent, sales to the military accounted for less than 25 percent of the American market.24

Throughout the 1950's, the U.S. microelectronics industry was still in its formative stages, with little sunk investment and almost no established commercial technological development trajectory. In fact, most of the early defense contracts went not to innovative start-ups like Transitron, Motorola, or Texas Instruments, but to established suppliers of soon-to-be-outmoded vacuum tubes, like General Electric, Western Electric, Sylvania, Raytheon, and RCA. As late as 1959, the big firms were awarded 78 percent of the federal research money for learning how to manufacture cheaper, more reliable transistors, even though they accounted, at that time, for only 37 percent of the transistor market. Smaller companies came to penetrate and, indeed, dominate the market almost in spite of Pentagon efforts.25

Still, military involvement in the fledgling industry played an important indirect role in encouraging new entrants and influencing industry structure. As Borrus, Millstein, and Zysman remind us:

23. John E. Tilton, International Diffusion of Technology: The Case of Semiconductors (Washington, D.C.: The Brookings Institution, 1971) pages 89-90. Cited in Baldwin, op. cit., page 71.
24. Norman Asher and Leland Strom, The Role of the Department of Defense in the Development of Integrated Circuits (Arlington, VA.: Institute for Defense Analyses, 1977). Cited in Borrus, et al., op. cit., pages 16-17.
25. Braun and MacDonald, op. cit., page 81, cited by Robert DeGrasse in Tirman, op. cit., page 91. Also, Robert B. Reich, The Next American Frontier (New York: Times Books, 1983) pages 190-91.

> The shift to the transistor and ultimately to the integrated circuit reshuffled the composition of the leading component manufacturers. Few of the leading producers of the electron tube managed to retain their component market positions in the new technologies. In this reshuffling process, defense and aerospace procurement created a market incentive for entrepreneurial risk-taking and thereby helped to spawn an independent sector of semiconductor component manufacturers.26

Indeed, as Utterback and Murray conclude, "Defense procurement and support for R&D stimulated the entry of new firms in the electronics industry in several ways, primarily through direct purchases. By providing an initial market at premium prices for major advances, defense purchasers speeded their introduction into use."27 A good example of this process is the early development of the integrated circuit, which combined formerly discrete electronic components, including transistors, on a single silicon chip. Like the transistor, the integrated circuit was developed without government funding, in this case by Texas Instruments, in 1958. By the middle of 1959, however, the Air Force had already awarded the company a $1.15 million, two-and-a-half-year contract to pursue further development of the technology; at the end of 1960, the Air Force followed this up with a $2.1 million contract to come up with special equipment and production techniques to enable the fabrication of integrated circuits en masse.28 Asher and Strom note that:

> As late as 1961, the industrial and scientific communities still voiced doubt as to the worth of integrated circuits from an equipment and systems viewpoint. To alleviate these doubts...the Air Force proposed the building of a representative piece of electronic equipment using integrated circuits. Under Air Force sponsorship, the building of a digital computer was introduced into the Texas Instruments production program. Two identical computers were

---

26. Borrus, et al., op. cit., page 15. Based on Ian Mackintosh, Microelectronics in the 1980's (London: Mackintosh Publications, Ltd., 1979) page 66, table II.
27. James Utterback and Albert Murray, The Influence of Defense Procurement on the Development of Civilian Electronics Industry (Center for Policy Alternatives, Massachusetts Institute of Technology, 1977) page 3. Cited in Borrus, et al., op. cit., page 16.
28. Borrus, et al., op. cit., page 17.

built: one with 9000 individual components and one containing only 587 integrated circuits.29

It is important to stress again that many of the major semiconductor innovations were achieved first by private firms without any government funding or assistance. This is particularly true for the three major technological innovations upon which the modern microelectronics industry has been built: the development of the transistor by Bell Labs, the creation of the integrated circuit at Texas Instruments, and the development of the planar process by Fairchild, a manufacturing technique which allowed for the economical production of reliable transistors and thus pried open a civilian market that could not have otherwise afforded to carry the costs of testing and redundancy which the military had assumed through the 1950's.30 Indeed, as Braun and MacDonald report:

> There is a division of opinion between those who claim that military funding of semiconductor development was essential to that development and those who see only the market provided by the Military as having been important. The latter group suggests that development would have occurred along the same lines and at the same pace had funds come from other sources. Whether such copious funds would have been available from other sources is perhaps less certain, but the argument reflects a feeling that much military research money was less than fully effective. Prolonged military support of the anachronistic micromodule project, unbridled military enthusiasm over molecular electronics, the relative weakness in the commercial market place of some of the larger firms to which the Military gave most support and the outstanding success of such firms as Fairchild, which usually avoided military involvement, are typically used to support this argument.31

It is true that particular R&D projects which the government chose to finance turned out to be failures. It is quite true, as well, that the work that led to integrated circuits, for example, or to the development of the planar

29. Asher and Strom, op. cit., page 17. Cited in Borrus, et al. op. cit., page 16.
30. Baldwin, op. cit., page 69.
31. Braun and MacDonald, op. cit., pages 141-42. Cited in Baldwin, op. cit., page 70.

process, was not directly financed by the government. It is also true, however, that such work was undertaken with the clear understanding and expectation that, if it were successful, there would be a massive government market to purchase the results. This is all the more significant because the firms that came up with these innovations were not well-established electronics producers. Before the development of the integrated circuit, the Defense Department's strong interest in semiconductors was only vaguely defined; it derived from its anticipation of the advantages improved semiconductor devices might impart. Thus, the fact that NASA and the Pentagon chose to buy semiconductors from any firm that came up with a superior design was critical to the promotion of the silicon-based integrated circuit technology that propelled the new merchant semiconductor firms to the forefront of the initial military and space markets and then to the top of the civilian market that soon emerged.

Moreover, as Nelson has pointed out, "the American defense and space programs were massive in comparison to European and Japanese public expenditures on R&D and were far more ambitious in terms of the technological advances sought than anything tried by other countries." "Before World War II," he writes, "American industry certainly was not laggard in electronics, but it was not noticeably superior to British industry; and German firms were considered the technological leaders. Several European firms were quick to develop transistors and, until the integrated circuit era, did not lag greatly behind American firms. But, by the early 1960's, largely as a result of these defense and space programs, U.S. firms were the acknowledged technological leaders in computers and integrated circuits."32

In 1963, for example, government programs removed financial barriers to integrated circuit production for both Texas Instruments and Fairchild; while the latter worked on a guidance computer for Apollo spacecraft, the former developed a missile guidance system for the Minuteman II. Between 1963 and 1965 the U.S. semiconductor industry was awarded twelve other government contracts for the incorporation of monolithic integrated circuits into military and space electronics systems. New companies were formed--Signetics, Siliconix, General Microelectronics, Molectro--attracted by potentially lucrative civilian applications of defense-sponsored technologies; likewise attracted to the burgeoning government market, older electronics firms like Raytheon, Sylvania, Motorola,

32. Richard R. Nelson, High Technology Policies: A Five-Nation Comparison (Washington, D.C.: American Enterprise Institute, 1984) page 44.

Westinghouse, and RCA began to move toward volume production of integrated circuits.[33]

On balance, then, early military (and space) programs clearly helped the U.S. electronics industry to achieve research and production superiority over its competitors, at least through the early 1970's. We can arrive at this judgment by applying our eight guiding questions to the particular case. The early military programs in question were designed to advance the state of the art of component technology, and military specifications for miniaturization, low power consumption, and high reliability coincided almost exactly with the likely needs of commercial users in the then fledging computer industry. Critically, the programs were designed to encourage competitive technology development and efficient manufacture (the latter because component technology was understood to be an intermediate input that would go into a wide variety of military and space systems). The microelectronics industry was at a formative stage of development, with little sunk investment and almost no established commercial technological development trajectory. The civilian firms participating included large established and small start-up companies, with the latter in particular eyeing potentially lucrative civilian applications of the defense-developed technology. Moreover, the technology was permitted to diffuse widely and rapidly between firms and into commercial uses. And there were no competing foreign R&D programs of significance aiming at parallel technology development. In sum, these characteristics delivered a highly beneficial and competitive trajectory of development for the U.S. microelectronics industry, thereby approximating the impacts to be expected from our U.S. rather than Soviet military-economy model. In fact, were the answers to our guiding questions to differ substantially, we shall argue, so would the commercial results. To develop this point, we turn next to the story of the military's early involvement with another new technology with potential commercial applications, the technology of numerical control.

<u>Numerical Control</u>. The U.S. machine tool industry and America's armed forces have carried on a long, intimate relationship regularly reinvigorated during the nation's wars--the industry's equipment being vital to the mass production of tanks, artillery, and munitions, wartime conditions, for better or worse, leading often to important technical advances in production equipment. Following just such a period of advances during World War II, this time in automatic mechanisms including computer calculation and feedback control systems, mechanical and electrical engineers began to apply these new technical capabilities to the problem of positioning machine tools. Numerical control

33. Borrus, <u>et al</u>., <u>op. cit</u>., page 17.

technology, which placed specifications for the movements of cutting tools on punched cards or magnetic tape, developed initially due to the Air Force's desire to fashion large, structurally complex metal parts as components for high-speed aircraft and missiles (integrally-stiffened wing sections, variable-thickness skins, etc.).

Throughout the 1940's, civilian machine tool manufacturers experimented with various applications of electronics technology to metalworking equipment. Many of these experiments involved forms of record playback control, a type of automation which required a machinist to fashion one part manually while the motions of the cutting tool were recorded on magnetic tape. As the name implies, the recorded tape could then be played back, duplicating the original cutting path and thus producing an identical part. As David F. Noble has pointed out in his extraordinarily detailed accounts of the development of numerical control, record-playback depended, for both programming and operation, on the reservoir of craft knowledge already available among skilled machinists. Because it used the skill of the machinist as its baseline for operation, he argues, the technology would have been readily accessible and easily diffused to most small and medium-sized metalworking shops, serving as a transition technology to full numerical control, and introducing the broad range of U.S. metalworking firms to the advantages of computer-assisted production as early as the 1950's.34

Noble claims that managers in the large machine tool firms saw in numerical control an opportunity to consolidate their shop-floor power and to drive smaller competitors out of the market. Toward these ends they supported the creation of an elite corps of NC programmers and the development of systems requiring computers that were beyond the financial reach of the small shops. Moreover, their interests dovetailed easily with those of the university-based computer engineers who developed numerical control, eager as they were to improve their professional status by developing methods for controlling industrial operations that created key positions in industry for mathematicians, programmers, and computer operators.35 In this view, Noble follows Harry Braverman, who argued that numerical control was developed primarily as a management tool to separate the conception and execution of metalworking tasks, thus

---

34. David F. Noble, Forces of Production: A Social History of Industrial Automation (New York: Alfred A. Knopf, 1984); also, David F. Noble, "Social choice in machine design: the case of automatically controlled machine tools," in Andrew Zimbalist, ed., Case Studies on the Labor Process (New York: Monthly Review Press, 1979).
35. Seymour Melman, Profits Without Production (New York: Alfred A. Knopf, 1983) pp. 104-5.

enabling the replacement of skilled metalworkers and machine setters with untrained operatives who needed only to fasten the workpiece and push a button to start the pre-programmed movements of the tool.36

There is undoubtably some truth to this argument; the early trade literature on numerical control is filled with extravagant claims made by engineers and machine-tool makers to the effect that NC technology would soon make craft skills obsolete.37 And there are case studies of metalworking firms, large and small, in which unskilled operatives do indeed produce metal parts simply by pushing buttons and watching the machines run. But, as Charles Sabel has written, decades of experience with operation of numerically-controlled tools has indicated, in country after country, "that economically efficient use of the equipment often requires that programmers have substantial knowledge of machining and that operators have substantial knowledge of programming. Otherwise programs tend to be roundabout, if they function at all; and machinists, who observe the metal cutting first hand, have no quick way of correcting them."38

More important for our purposes, however, is a point that Noble, himself, has made: "Air force performance specifications for four- and five-axis machining of complex parts, often out of difficult materials," he writes, "were simply beyond the capacity of either record-playback (or manual) methods."39 It should be no surprise then that the low cost and relative simplicity of record playback did not particularly interest Air Force planners; Noble shows, in fact, that there was no evidence of interest in cost-minimization at any time during the process of technological development. As Sabel has argued, it was the product-specific nature of military programs more than the desire (which did exist in some firms) to de-skill the workforce that sent the NC segment of the U.S. machine tool industry along a technological trajectory particularly unsuited to the needs of most potential commercial users:

---

36. Harry Braverman, Labor and Monopoly Capital: The Degradation of Work in the Twentieth Century (New York: Monthly Review Press, 1974) pages 197-206.
37. see Harley Shaiken, Work Transformed: Automation and Labor in the Computer Age (New York: Holt, Rinehart, and Winston, 1984) pages 75-6. See also Braverman, op. cit., page 202.
38. Charles F. Sabel, Work and Politics: The Division of Labor in Industry (London: Cambridge University Press, 1982) page 66; also see Shaiken, op. cit. pages 66-135.
39. Noble, in Zimbalist, ed., op. cit., page 29.

> Whatever the visionary pretensions of some of its designers and their admirers, the first numerically controlled machine tools were in fact built as special-purpose machines, suited to the exotic task of contouring complex aerodynamic surfaces such as turbine blades and wings. Had the U.S. Air Force not subsidized the development of the first machines through cost-plus contracts with the manufacturers, they would certainly not have been produced as quickly as they were. Because of this subsidization, the machines met the Air Force's needs and virtually no one else's.[40]

Indeed, it would have been more propitious from a commercial standpoint had the machine tool industry been encouraged to develop more than one automatic machining technology--expensive, sophisticated numerical control, for subsidized military work and a more accessible, economical record playback system that might have paved the way for the use of today's compact microprocessor-based NC tools in the majority of small- and medium-sized metalworking shops. Instead, the Air Force stepped in at the beginning of a new cycle of the industry's development when machine tool firms were investing in several variants of record playback and heavily subsidized a single technology, guaranteeing lucrative contracts to an isolated core of machine tool and control manufacturers who developed numerical controls, and creating a limited, highly-specialized market for NC tools through its procurement policies.

Between 1949 and 1959, when the Air Force discontinued its formal support for software development, the military spent at least $62 million to research, develop, and diffuse numerical control technology, most of it originating at MIT's Servomechanism Laboratory.[41] Here were created the basic NC hardware and a standard programming language, APT (Automatically Programmed Tools), a language so sophisticated it could be applied to control the motions of a cutting tool along five axes in unbounded space. But software this versatile turned out to be virtually irrelevant to the needs of most small- and medium-sized shops. In Sabel's words, APT possessed "all of the sophistication necessary for describing superhuman manipulation, but none of the generality and simplicity required to express economically and in an easily learned way the huge range of everyday machine operations."[42] Or, in the words of Harley Shaiken, APT, for most metalworking

40. Sabel, op. cit., page 69.
41. Noble, in Zimbalist, ed., op. cit., page 25.
42. Sabel, op. cit., page 69.

operations, was the equivalent of "using an M-1 tank to drive to work."43

As Sabel notes, "it took almost twenty years and breakthroughs in programming methods (for example, the creation of MDSI's Compact II) and computer design (for example, the invention of microprocessors that opened the way to computer numerical control) before the original idea of numerical control was embodied in practical, general-purpose machines."44 Yet, because the initial use of APT created programs which could not be easily translated, it continued to be the de facto industry standard long after a new generation of simpler programming languages became commercially available. As Nobel states, "Companies that wanted military contracts were compelled to adopt the APT system, and those who could not afford the system, with its training requirements, its computer demands, and its headaches, were thus deprived of government jobs. The point here is that the software system which became the de facto standard in industry had been designed with a user, the Air Force, in mind."45 Not surprisingly, a 1981 survey indicated that "while 46% of the firms with a large number of NC machine tools (11 or more) used APT, only 15% of the firms with a medium number (5-10) and 13% of the firms with a small number (less than 5) used APT."46

Air Force procurement practices skewed the structure of the machine tool industry's NC segment not only through its choice of technology, but also through its practice of favoring with its contracts the core of suppliers it created in the 1950's, many of whom have remained major producers into the 80's.47 Between 1949 and 1953, only one company, Giddings and Lewis, was sufficiently interested in the new technology to invest any of its own funds, this despite a massive campaign mounted by the Air Force and MIT to interest machine tool builders and the aircraft industry in numerical control. In 1955, however, promoters of the technology successfully changed the specifications for stockpiling machine tools in the Air Material Command budget allocation from tracer-controlled to numerically-controlled machines. The Air Force then set about creating a market: it paid for the purchase, installation, and maintenance of over 100 NC machines in prime contractor's factories and

43. Shaiken, op. cit., page 100.
44. Sabel, op. cit., page 69.
45. Nobel, in Zimbalist, ed., op. cit., page 28.
46. see the excellent study by Paul Ong for "NC Machine Tools," in Industry and Trade Strategies, "Programmable Automation Industries (Report to the Congressional Office of Technology Assessment [contract no. 333-2840] April 1983; mimeo, Berkeley Roundtable on the International Economy (BRIE), University of California, Berkeley.
47. ibid.

funded training programs to teach the contractors how to use the new technology. The results were impressive: between 1951 and 1957, research and development expenditures in the U.S. machine tool industry multiplied eight-fold.48

The Air Force practice of "seeding," that is, the direct placement of NC tools for use in selected firms, seems to have provided these firms with a dominant hold on the numerically-controlled segment of the machine tool market. Combined with the high price and technical complexity of the tools, Air Force contracts worked to restrict the market to the aerospace industry and similar specialized uses, preventing until the early 1980's the emergence of an American NC tool segment focused explicitly toward broader-based commercial applications. When advances in computer and semiconductor technology made possible the development of NC equipment that could be programmed easily to perform the wide range of tasks that make up the majority of machining jobs, few American firms realized the potential; American experience simply taught the industry that computer-controlled machine tools could be economically employed only in large firms for the manufacture of complex components.49 By contrast, the Japanese machine tool industry shifted rapidly to the production of small, NC equipment; Japanese production of numerically-controlled lathes and machining centers increased ten-fold between 1970 and 1979.50

Air Force involvement certainly helped to stimulate demand for sophisticated American-made NC tools throughout the civilian aerospace industry, which traditionally accounts for between 10 and 20 percent of the NC tool market.51 Because the technology that helped to produce intricate aircraft parts for the military could be easily applied to the production of commercial planes, and because the military subsidized the cost of technological development, it made perfect sense for civilian aerospace firms to adapt military NC technology to their own uses. Indeed, Air Force programs created a core of technical expertise within the aerospace industry which facilitated rapid diffusion of the technology into private aerospace companies or the civilian divisions of aerospace companies which also built military planes. There was no complementary effort on the part of any government agency, however, to promote the technology in other manufacturing

---

48. Noble, in Zimbalist, ed., op. cit., page 25.
49. One exception was Dana Corporation's Summit product center in Bozeman, Montana. Noted in Michael J. Piore and Charles F. Sabel, The Second Industrial Divide: Possibilities for Prosperity (New York: Basic Books, 1984) page 218.
50. ibid.
51. Ong, op. cit. 1983.

sectors. In Japan, by contrast, MITI sponsored the rapid diffusion of NC technology throughout the Japanese economy, operating through a set of regional technical assistance centers--financed from bets collected on company-sponsored bicycle races--to teach small- and medium-sized metalworking shops how to use the new technology. This was combined this with an economy-wide production strategy that intentionally created a market for small machine tools.52

The consequences for U.S. competitiveness in NC machine tools seem clear. By 1978, only 3.7 percent of the metalworking equipment used by the machine tool industry itself was numerically controlled; by 1979, more than two decades after the technology became commercially available, only 2 percent of all machine tools used in the United States were numerically controlled.53 Although the total number of NC machine tools almost doubled between 1978 and 1982, imports as a share of the value of U.S. consumption rose from a little over 23 percent in 1980 to more than 35 percent by 1983, almost 90 percent of them from Japan.54 In 1984, two-thirds of the numerically-controlled turning machines and three-quarters of the NC machining centers installed in U.S. firms were bought from foreign firms.55 During the first seven months of 1985, more than 50 percent of all NC tools used in the United States came from overseas.56

Although significant differences in industrial structure surely played an important role in shaping the competition for this, the most rapidly growing segment of the machine tool market, government policy had an overriding influence.57 Both Japan and the United States sponsored developmental programs; the commercial implications of the U.S. effort can be read clearly in the answers to our set of guiding questions as applied to this case: The early military programs were designed to meet specific military product applications, the machining of complex aerodynamic

---

52. ibid.
53. Melman, Profits Without Production, op. cit., pages 8 and 10.
54. U.S. Department of Commerce, International Trade Administration, "A Competitive Assessment of the U.S. Manufacturing Automation Equipment Industries" June, 1984, pages 22-25; pages 36-37..
55. U.S. Department of Commerce, U.S. Industrial Outlook 1985, (Washington, D.C.: 1985), Chapter 21 "Metalworking Equipment" page 21-7.
56. "Machine Tools Industry Update," Prudential-Bache Securities, November 4, 1985, prepared by Christine Chien and Laura Conigliaro.
57. see Ong, op. cit., for a description of contrasting industrial structures in the U.S. and Japanese NC machine tool sectors.

surfaces such as turbine blades and wings. Military requirements led to the development of a technology and a programming language completely out of step with the commercial market requirements of the largest segment of the involved industry, needs for generality and simplicity and a technique--such as record playback--that might have economically automated the huge range of everyday machining operations in a way that was easily accessible to the existing work force. The Air Force practice of "seeding" particular firms with special-purpose machine tools subsidized by cost-plus contracts encouraged these firms to undertake large investments that could not be amortized through volume commercial production. Commercial product development was inhibited and the attention of designers was directed away from efficient, generalizable production technologies even though the industry was beginning to experiment with a wide range of automatic techniques. Air Force contracts rewarded large aerospace and automotive firms that could afford the equipment and seems to have helped their major suppliers to establish a position of long-term dominance in the domestic industry. Military-sponsored advances were too exotic and expensive to diffuse into commercial applications, either at home or abroad. Foreign competitors, particularly Japan and West Germany, pursued strategies explicitly aimed at the preponderance of small- and medium-sized job shops and were thus especially well-positioned to storm the U.S. market when development of the microprocessor and a simpler programming language made numerical control widely accessible for everyday machining operations. In sum, the military's early involvement created a dual industry structure and contributed mightily to the development of a military-dependent and uncompetitive NC machine tool sector in the United States.

III. The Pentagon and the Firm

At this point, we have applied our set of guiding questions to two technologically advanced sectors, and it is clear that arguments can be made on both sides of the defense-economy debate. There appears to be no *a priori* way to determine whether commercial impacts resulting from any particular military program will be positive or negative. Nevertheless, it is possible to examine the recurring factors associated with defense research and procurement that create the conditions for both positive and negative commercial effects. It then becomes possible to determine which factors are currently most prevalent.

Two Strategies. High-technology firms try out a variety of competitive tactics in the marketplace, most of which combine features of two analytically distinct marketing strategies. The first strategy involves an attempt to fully exploit the commercial potential of the current product generation--a tactic that requires an emphasis on increased efficiency (low cost, high quality) in the firm's manufacturing operations. The second strategy--more common in the high tech sectors--involves an attempt to focus, instead, on product innovation, a focus that requires more of an organizational emphasis on research and development.

Put in slightly different terms, the first strategy suggests an attempt to move all the way down the experience curve of the current product generation, building up a solid customer base and distribution system, and thereby truncating the rents on innovation that would otherwise accrue to firms that choose to concentrate on the development of new product ideas and prototypes. In this case, the firm plays the role of "technology follower," building up a store of manufacturing and merchandizing expertise by pursuing ever more efficient production of product innovations developed elsewhere, building up profits by successfully adapting those innovations to the specific needs of its customer network.

In contrast, high tech firms often choose to be technology leaders, attempting to capture market share by emphasizing research, design, and development, by always being the first to start down the *next* product generation's experience curve in order to gain competitive advantage in the markets of the future. To be successful, this strategy must rest on a comparative advantage in design and engineering; it depends, also, on the ability to make a profit by selling or licensing new inventions to firms that have chosen to pursue the technology follower strategy. That ability is threatened, however, to the extent that the innovations are easily copied and upgraded, enabling the follower firms to capture substantial product market share with the new technology before the leader has fully realized the financial fruits of its invention. Thus, the pursuit of manufacturing efficiency is important for technology leaders, too--in this case, it enables them to keep collecting rents on a prior innovation in the market for the current product generation until the next generation is ready to come on line.

Intentionally or not, government policies toward industry also will tend toward promoting one or the other of these strategies; a pronounced tilt in either direction can occur as often by default as by design. Public policies can promote technological innovation--direct subsidies for R&D, procurement policies that mandate state-of-the-art performance, the payment of price premiums above actual cost in order to subsidize experimentation and promote improvements in product quality and reliability. Alternatively, government policies can promote the rapid achievement of production and marketing efficiencies, through government-sponsored demonstration projects, purchaser as well as producer subsidies, government procurement that specifies standards for inputs and outputs rather than state-of-the-art performance, and the promotion of rationalization and mergers to obtain economies of scale.

The latter model resembles the Japanese approach to developing emerging industrial sectors, at least during the period of technological catch-up leading up to the mid-1970's. It also characterizes many government-sponsored programs in the United States--politicians in both countries prefer large demonstration projects their constituents can see to expensive R&D programs whose payoff (if any) occurs far in the future. In many cases, however, the U.S. Department of Defense has pursued the alternative approach.

Pentagon policies often are designed explicitly to advance the technological state-of-the-art. Programs that focus the attention of defense contractors on being the first to get started on each new experience curve are given higher priority than the achievement of production efficiencies because the relevant axis of competition (in this case, with the Soviets) is not price or use-value, but the achievement of absolute technological superiority and the establishment of an effective deterrent--in a very real sense, non-use value.

These sorts of development policies can make good commercial sense as well, but only under particular cirumstances. These conditions are really just a list of particular answers to our set of guiding questions: besides a focus on advancing the general technological state-of-the-art (as opposed to an emphasis on specific military product applications), the military program must encourage competitive product development and efficient, generalizable production technologies, provide outlets for volume production so that manufacturers can realize learning economies and large economies of scale over long production runs, occur at an early stage in the affected industry's life-cycle (before the direction of commercial development has been defined and confirmed by investment), and most critically, allow relevant military advances to diffuse into commercial applications.

When military programs follow this pattern, they can help to promote commercial competitiveness. When they do not, they contribute instead to production inefficiencies which can undermine both of the competitive marketing strategies outlined above. In either case, moreover, production inefficiencies are actually encouraged by the rigid governance structure that comes to characterize firms working under contract to the Pentagon. It will be useful, therefore, first to describe this structure in some detail, contrasting it to the internal governance structures that typify high tech firms which compete successfully in world markets. We will then proceed to examine particular features of the Pentagon's research and procurement process, paying particular attention to their impacts on one or the other of the dominant marketing strategies pursued by high tech firms, volume production and, especially, product innovation.

Firm Governance Structure. The Pentagon's practice of contracting with civilian companies to fulfill much of its research and most of its production needs has given rise to a unique organizational form, the military-industrial firm, whose characteristics differ sharply, in both overall strategy and routine operation, from those usually associated with commercially-successful high tech firms.58 It is the process of differentiation, the process by which the military research and development effort begins to lose its symbiotic connection to civilian industry, with which we are most concerned. For standard operating procedures which may make perfect sense for achieving military objectives may have perfectly awful consequences, as we have seen, for the ability of U.S. manufacturers to remain competitive in world markets. And because the routine and strategic economic behavior of firms is significantly shaped both by their interactions with other institutions and by changes in the tasks they must perform in order to survive, the increasing involvement of non-defense firms in military programs threatens to embed poor competitive performance into the very processes by which these normally market-oriented firms routinely structure their economic behavior.

The Pentagon can dominate a contracting firm to the extent that it can control vital elements in the firm's environment which, in turn, constrain the choices the firm can make about how to behave--about how to develop a process for making strategic choices and for organizing its day-to-day operations so as to make those choices effective.59 In monitoring the performance of a contracting firm during the development of a new weapons system, for example, the Pentagon exercises each of the forms of control John Zysman has identified as defining the relationship between a "dominant" and a "subordinate" institution: the Pentagon, to a great extent, commands the resources required by the contracting firm; it determines what tasks the contracting firm will perform; and it establishes the rules and

---

58. Two useful theoretical studies of the military-industrial firm are: John Francis Gorgol and I. Kleinfeld, The Military-Industrial Firm (New York: Praeger, 1972) and Seymour Melman, Pentagon Capitalism (New York, MacGraw Hill, 1970). Other important analyses are John R. Fox, Arming America (Harvard University, Graduate School of Business Administration, 1974) and Jacques S. Gansler, The Defense Economy, (Cambridge, MA.: MIT Press, 1980). Fox and Gansler are both experienced administrators in military-industrial firms and the Defense Department. Melman provides an excellent summary of Fox in Appendix III of Profits Without Production, op. cit., entitled "How the Military Economy Maximizes Cost," pages 301-4. Another useful summary analysis is provided by John E. Ullmann, "The Pentagon and the Firm," in Tirman, ed., op. cit., pages 105-22.
59. Ullmann suggests discussing the Pentagon's controlling influence in terms of the central characterstics of the decision power of a typical commercial enterprise--the degree of control over "what to make, how to make it, in what quantity, at what price, and with whose invested money." ibid., page 108.

procedures that the contracting firm must follow in performing its tasks.60

The Pentagon's extensive, product-specific involvement in the workings of a commercially-oriented firm can quickly undermine the firm's competitiveness. Most critically, if the Pentagon gains primacy as a source of financial support, the firm's attention will be drawn away from market signals and toward the establishment of routes of influence on decision-makers in the Pentagon. The contracting firm begins to mimic the bureaucratic structure of the Pentagon itself in order to facilitate effective communication, isolating itself, in the process, from channels of communication with civilian customers.

The firm's development of channels for influencing Pentagon strategists will be more pronounced--that is, reflected more clearly in new organizational routines--the more continuous and widespread are the firm's interactions with the military bureaucracy. One is hard-pressed to think of a more sustained set of interactions between two organizations than that produced during the process of development of a new weapons system. As Zysman writes:

> Every small technical change must have performance consequences, and it is for the user, not the manufacturer, to decide which mix of characteristics is most appropriate. Moreover, the process of on-going surveillance will involve interaction at all levels of the organization between financial control personnel, engineers, strategists, and the like. The borderline between the two groups may, in fact, blur.61

Although firms working under contract to civilian customers surely expect a certain amount of customer oversight regarding the design of technical specifications and the progress of production, military contractors (and, often, subcontractors) must endure constant supervision over all aspects of their operations, from payroll to inventory control. A coterie of Pentagon supervisors moves in to monitor the contractor's compliance with the military's central directives, a system of behavioral rules primarily contained in the Armed Services Procurement Regulations (ASPR) and supplemented by The Defense Procurement Handbook. According to Fox, ASPR comprised 100-125 pages when it was

---

60. John Zysman, Political Strategies for Industrial Order: State, Market, and Industry in France (Berkeley: University of California Press, 1977) pages 173-76.
61. ibid., page 175.

first put together in 1947; by 1973, the rules covered 3,000 pages in loose-leaf format, with monthly replacement pages adding to its bulk on a continuing basis.62

High technology companies, small or large, need to be quite flexible when introducing new products or production techniques. Thus, successful firms tend to be decentralized and multi-divisional, with a product development office operating within each division and in close contact with the divisional departments responsible for engineering, production, and sales. The separate departments of product development must monitor all product applications very closely, so that they can identify opportunities for new product lines, send the product research staff off in new directions, and work with the divisional sales staff to respond quickly and creatively to customer needs and suggestions.63

The product development process in military-industrial firms could hardly be more different. The Defense Department decides what it wants the firm to make. Bids are solicited or a supplier is chosen outright. Indeed, because the Pentagon generally relies on its prior technological experience with a contractor in order to evaluate the contractor's claims for the expected technical performance of a proposed system, established firms tend to be favored over more innovative start-ups. In addition, the Pentagon prefers to accept bids only from firms it considers "qualified sources," that is, firms which have existing plant and equipment capable of handling both the development and production portions of a proposed contract.64

Because of its overriding focus on the achievement of technically superior weapons systems regardless of cost (and it seems, sometimes, regardless of performance), the Pentagon's overall attitude toward product development resembles nothing so much as the old comic strip drawing of a cave woman and her husband, who has been working on his new invention, a crude stone wheel. "That's very nice, dear," says the wife, "but how are you going to hit somebody with it?"65

Similarly, the Pentagon's standard practice of "planned concurrency" during the development and production process sacrifices the quality of the product to the military's

---

62. Fox, op. cit., page 14.
63. see Ullmann, in Tirman, ed., op. cit., page 109.
64. Gansler, op. cit., footnote 17, page 304.
65. Ullman, in Tirman, ed., op. cit., page 109.

needs for "minimizing acquisition cycle time."66 As Melman explains:

> In industrial and other enterprises it has long been standard practice to prepare schedules for the steps to be taken from the inception of a new product to its introduction on the market. Typically, a product schedule includes a research and development phase, followed by product design and the preparation and testing of a prototype. Modifications are then made to eliminate undesirable features and a revised design is drawn up for further testing. This process repeats until a prototype has withstood operational tests that satisfy the management as to the adequacy of the product. Not until then does the new model go into production.67

The idea of concurrency, however, is to perform many of these steps simultaneously, based on the assumption that all intervening functional operations can be carried out at the same time. Instead, Melman notes, "what usually happens is that defects in the products are discovered either at the factory or while in use by the customer. Then modifications are made on the already produced and delivered equipment. This is the most expensive way known to carry out revisions in industrial design, but it is a procedure ordained as standard practice in the regulations of the Department of Defense."68

Thus, within an explicitly protectionist environment, the Pentagon can use manifestly un-competitive incentives--sole-source procurement, cost-plus contracts, etc.--to structure the organization of production to suit its own purposes. Unlike the positive elements of our Pentagon involvement model--a mix of joint research and development, intense internal competition, and external protection which, except for its lack of explicit orientation to world markets, resembles Japanese-style "controlled competition"--these aspects of standard Pentagon practice tend to drive a wedge between contracting firms and their commercial markets. More and more, a contracting firm finds that it must substitute procedural channels to and the product development agendas of Defense Department technocrats (and their Congressional patrons) for merchandising channels to

---

66. U.S. Department of Defense, Department of Defense Instruction, no. 5000.2, March 19, 1980, pages 12-13. cited in Melman, Profits Without Production, op. cit., page 213.
67. Melman, ibid. page 212.
68. ibid. pages 212-13.

and the rapidly shifting demands of consumers in international markets for high technology products. Whereas commercial firms are typically constrained by the balance which must be struck between the price and volume at which their products can be sold in the marketplace and the cost at which they can be produced, defense contractors must concentrate on tailoring their product mix and technological wizardry to performance criteria specified by Pentagon officials. A great deal of organizational energy is therefore spent merely on devising ways in which to better anticipate and influence those criteria.

<u>One Step Forward, Two Steps Back</u>. It should be clear, by this point, that although Pentagon involvement in the development of new technologies is not <u>necessarily</u> good or bad from a commercial standpoint, its impact on the day-to-day operations of commercial firms is likely to prove quite disruptive. Thus each of the methods we will now discuss by which the Pentagon can promote competitiveness--volume procurement, "buy American" provisions, payment of price premiums, direct subsidies for R&D, diffusion of innovations by defense-trained research personnel--can shade easily, almost imperceptibly, into threats to the competitive performance of contracting firms--pork-barrel procurement, damaging protectionism, sole-sourcing and cost-plus contracts, technological over-sophistication and narrowly-applied R&D, over-specialized personnel hamstrung by export and publication controls. Each of these forces is present during the course of every military program that involves a commercial firm, and each is reflected in the set of guiding questions with which we are attempting to determine the commercial implications of particular military programs. The Pentagon's increased interest in contracting with firms in the commercial mainstream is worrisome precisely because the negative aspects of the procurement process can systematically corrupt the successful competitive habits of innovative high tech firms.

The following features of the Pentagon research, development, and production process are grouped with reference to the dominant marketing strategies outlined earlier. The first set is most likely to aid or eventually undermine a volume production strategy; the second set will tend to promote or subvert a strategy of product innovation, depending on the answers to our set of guiding questions with respect to the particular military program which brings these features into play.

Volume Production Strategies: The Role of Military Procurement. Clearly, Defense Department procurement has had a substantial effect on the development of commercial markets for many emerging products. Military hardware contracts accounted for 16.9 percent of the durable manufactured goods sold in the United States between 1960 and 1973; in the ten years following up through 1983, defense hardware contracts averaged 10.9 percent of total U.S. durable manufactured goods production. These purchases have been most concentrated in high technology sectors such as aerospace, electronics, and communications--70 percent of the Pentagon's major hardware purchases over the past three decades have been components of advanced technological systems for aircraft, missiles, electronics, and communications equipment.69 In the wake of the Reagan Administration's unprecedented military build-up, defense procurement is again expected to expand the markets for several types of high tech products into the 1990's. Between 1983 and 1987, for example, defense spending for semiconductors was projected to increase by more than 18 percent; the civilian market was expected to grow by 12 percent. In the computer industry, military sales were expected to increase by more than 16 percent while commercial sectors grew a bit less than 13 percent. The same uneven pattern was expected to obtain in communications (11.6% for defense; 5.3% for commercial applications) and engineering and scientific equipment (9% for defense; 5.6% for commercial applications).70

Protectionism. In the short term, the Pentagon promotes the competitiveness of American manufacturers through a series of "buy American" provisions written into its procurement regulations. These provisions offer a degree of import protection for American producers by requiring the Defense Department to purchase domestic products if the added cost of so doing does not exceed 50 percent. The Pentagon was exempted, in fact, (along with the Energy and Transportation Departments) from the Trade Agreements Act of 1979. That act sought to reduce protectionism in government procurement, largely at the request of U.S. high tech firms who were trying, then as now, to penetrate government markets in Japan and Western Europe.71 As with the rest of the practices discussed in this section, however, this one is characteristically double-edged. Protectionist policies insulate American

---

69. Hugh G. Mosely, The Arms Race: Economic and Social Consequences (Lexington, MA.: D.C. Heath, 1985) page 80.
70. Reich, The Next American Frontier, op. cit., page 192.
71. Ira C. Magaziner and Robert B. Reich, Minding America's Business: The Decline and Rise of the American Economy (New York: Vintage, 1983) pages 226-27.

manufacturers from international competitive pressures to innovate, so the "competitiveness" such policies protect is more apparent than real. As Lester Thurow has written, "Military spending is a captive market for American manufacturing. Americans don't ask for competitive foreign bids on military equipment. If they did, all of our naval ships would be made in Japan."72

Sole-sourcing and Cost-Plus Contracts. As usual in cases of direct protectionism, "buy American" provisions of this sort involve no quid pro quo on the part of producers to ensure that they will take advantage of the artificial relaxation of competitive pressure for the development of high-quality products at low cost. After all, the Defense Department has no interest in the successful marketing of new products; its main interest in procurement is ensuring the timely delivery of technologically-superior weapons systems by stable military suppliers. Indeed, more than 65 percent of all defense contracts are routinely awarded without competitive bidding.73 Even when firms must compete for Pentagon funds, moreover, the bidding process is effectively subverted by the award of cost-plus contracts, which provide the firms with an incentive to maximize their costs of production in order to expand the federal subsidy. Indeed, production efficiency is actually penalized under this system since profits are calculated on the basis of total costs.

Of course, even among defense contractors, competitive rivalry is often fierce during the early research and development phase of a project, when a few very large firms are allowed to bid for programs likely to be worth billions of dollars over several years.74 Still, this is a type of competitive behavior quite unlike that required for success in world markets. Firms have every incentive, when competing for access to Pentagon funds, to pour millions of dollars into enriching the presentation of their proposals, because the Pentagon eventually pays for all proposal costs

---

72. Lester C. Thurow, The Zero-Sum Solution: Building a World-Class American Economy (New York: Simon and Schuster, 1985) page 100.
73. Baldwin, op. cit., Table II-1, page 13. Gansler notes, as well, that "even the DOD acknowledges that over 60 percent of defense dollars are awarded on a sole-source basis, and that the share of the dollars in this category has been increasing." Jacques S. Gansler, The Defense Economy, op. cit., page 93.
74. Gansler argues that in order to understand how the Pentagon's competitive bidding process paradoxically bids up costs, one must distinguish between competition for the initial contract award and competition during the much longer product development phase of a project. Gansler, op. cit., pages 92-93.

as part of the project's routine overhead expenses. At the same time, firms often compete on the basis of unrealistically low bids, because they know that the costs of any changes made later on in a project will be fully reimbursed through Pentagon progress payments.75 Consequently, the costs of an average contract increase by at least 45 percent over the life of a typical project; as Gansler notes, this significantly increases the total amount of contract dollars awarded without benefit of competition.76

Cost-plus provisions make some sense given the Pentagon's primary contract objective: the achievement and maintenance of technological superiority. Having already eliminated the very risky process of identifying a new product and its potential market, the Pentagon now attempts to enable the contracting firm to escape much of the financial risk associated with long-term product development. Thus, military suppliers are rarely under any pressure to achieve high quality at the lowest possible cost; the incentive is rather to pursue high quality regardless of cost.. And this objective is kept in focus throughout the bidding process, as most defense dollars are awarded, not on the basis of price, but as the result of expected technical performance. In sum, as Gansler writes:

> Because...almost all of the defense acquisition dollars are awarded as a result of technical competitions, changes to a single firm's contract after it has won the original competition, or sole-source awards to the only firm involved in a particular project, and since the majority of sub-contract dollars are similarly awarded to sole-source producers or to a firm's sister divisions (as a result of vertical integration), well over 90 percent of the defense contract dollars are not awarded on the basis of price competition or in the presence of any incentives that would drive down the costs.77

---

75. ibid., footnote 19, page 296. Low development cost estimates help the Pentagon to get programs through Congress in two ways--they give the appearance of lower costs and also of lower profits, because the formal profit rate is calculated based on the initial dollar bid. Cost overruns are reimbursed by the government separate from the negotiated profit rate.
76. ibid., page 75. This figure is based on Gansler's analysis of profit rates on completed prime contracts for fiscal years 1959-1974. A typical cost-plus-fee contract grew by 75 percent.
77. ibid., page 93.

As Baldwin notes, much DOD procurement is not of parts, but of highly integrated electronic systems, often in highly specialized form, such as naval tactical onboard computers or sensor surveillance equipment. In his words, "in such a highly interrelated system, needs for system compatibility, critical time path considerations, and ready availability of essential technical information and operating data make some sole-source procurements from established producers inevitable."78 Indeed, not all sole-source procurements are anti-competitive; some occur in response to unsolicited proposals from smaller firms and new entrants. Unfortunately, notes Baldwin, sole-source contracts are usually not used effectively to reduce barriers to entry and promote competition. Instead, unsolicited proposals are most often "used as the basis for issuance of competitive invitations to bid. The result is to discourage submission of unsolicited proposals, expecially the more innovative and potentially valuable to both the contractor and DOD."79

Production Volume. Pentagon procurement can aid the process of commercialization of new technologies by providing manufacturers with a market large enough to accelerate learning and achieve greater economics of scale. Such volume is especially crucial to the achievement of lower costs in military projects undertaken within the framework of cost-plus contracts. But Pentagon production decisions--including production location as well as volume--are often the result of pork-barrel politics; there is no market mechanism through which to assess demand or market saturation (what might be appropriately termed "overkill," at least in this context). In contrast, as John Ullmann writes, "Production volume is normally subject to major decisions on the part of management after assessing the market to be served, its prospects for expansion, or the possibility of opening up new markets or market segments and the question of whether to design the manufacturing system for mass production or small batch output."80

These decisions can be influenced significantly by the Pentagon, but that influence depends mightily on the size of the military market relative to the total market for the industry's products. The influence of Pentagon procurement on the developmental trajectory of the semiconductor industry was predictably massive, for example, when the military accounted for 95 percent of the market. As we shall see in our discussion of the Pentagon's Very-High-Speed Integrated Circuit program (VHSIC), however, the military's ability to influence the commercial direction of

78. Baldwin, op. cit., pages 76-77.
79. ibid.
80. John Ullmann, in Tirman, ed. op. cit., page 111.

the industry today is clearly inhibited by the fact that its share of total semiconductor sales ranges between 10 and 15 percent. Still, the military's share may be large enough to effect decisions at the margin of technological advance; when the military's share--and funding dominance--covers the cutting edge of the industry's product market, substantial help or harm may be done depending on how close the military's needs are to the needs of the industry's mainstream market.

Production Innovation Strategies: Advancing the State-of-the-Art. By setting performance standards higher than those typically encountered in civilian technological development, military programs can challenge scientists and engineers to imagine new technological frontiers. The Pentagon can promote successful innovation not only by refusing to specify input and output standards, but also by expanding production faster than it would otherwise grow, thus accelerating an industry-wide slide down the experience curve. Moreover, the Pentagon can promote successful technology development by providing the funds which enable manufacturers to spread their technological bets. As one Pentagon economist puts it:

> Defense sets goals that are difficult to meet; our new programs often tax the limits of technology. Only the Department of Defense's budget is rich enough to experiment with new approaches to complex problems. It is my belief that we cannot foretell exactly the future path that technology must take in the quest for new commercial applications and solutions to non-defense problems. In the same sense that we seed the clouds in the hope for rain, so too we seed our research laboratories in the hope of finding solutions to difficult problems.81

Because technological development is inherently uncertain, particularly at the earliest stages of generic research, multiple approaches are essential to improve the odds that the research will pay off. As John Zysman and Stephen Cohen have argued, this strategy is analogous to covering the table at the roulette wheel; each bet is valuable precisely

81. find reference.

because it is different from the others.82 Spreading one's technological bets is therefore the most intelligent and conservative technological development strategy for individual firms as well as the Department of Defense--as long as the various approaches are not constrained to conform to specific military products or systems.

Price premiums. Thus, in addition to enlarging the volume of production through its procurement contracts, the Pentagon uses cost-plus contracts (which guarantee a specified percentage of costs as profit) to subsidize the development of pioneering technologies and improvements in product reliability which would not be profitable in commercial markets. This practice has some rather large drawbacks, of course, as we have seen. We should not lose sight of the fact, however, that the Pentagon's willingness to pay a premium over actual costs constitutes a government subsidy which can spur the development of new technologies.

Because defense contractors receive periodic cost-reimbursements during the lengthy development phase of a new weapons system, they can use the Pentagon, in effect, as a source of interest-free working capital. This is especially useful for high tech firms whose products are often on the cutting-edge of technological development and where working capital thus accounts for a particularly large proportion of total investment. Magaziner and Reich illustrate the utility of such Pentagon financing to an individual contractor: one supplier, they report, showed a 6 percent return on sales in its civilian operations and a 5.5 percent return on sales in its military operations. Because of Pentagon progress payments, however, the same supplier showed a return on investment of 19 percent in its civilian business and a whopping 48 percent in its military contract work.83

Technological over-sophistication. Still, regardless of its impact on the health of an individual company's financial balance sheet and despite popular perceptions to the contrary, there is little evidence that technical work done for the Department of Defense has routinely yielded substantial benefits, in terms of commercial spinoffs, to the civilian economy. As we shall show in a moment, the spinoffs that have occurred all involve highly expensive and sophisticated aircraft and electronics-based products which, in some cases, require little adaptation between military and civilian uses. In terms of general consumer products,

---

82. Stephen Cohen and John Zysman, Manufacturing Matters: The Myth of the Post-Industrial Economy, unpublished draft manuscript, Berkeley Roundtable on the International Economy (BRIE), University of California, Berkeley, January 7, 1986.
83. Magaziner and Reich, op. cit., page 228.

one 1975 study found perhaps 5 percent, but not more than 10 percent of spinoff per military research dollar.84

Mary Kaldor has argued that the military product emphasis of much research and development in the United States typically results not in revolutionary innovations but rather in "incremental improvements to a given set of performance characteristics through often radical changes in hardware."85 Noting, for example, that military aircraft require far more maintenance time than do commercial aircraft, she quotes the designers of the successful Boeing 727: "the more an airliner resembles a bomber, the less successful it will be."86 In his highly influential work, National Defense, James Fallows argues that as the result of such technical over-sophistication, the creation of what Kaldor has termed a "baroque arsenal," the U.S. armed forces are stuck with a stock of military hardware too complex to use on the battlefield and too expensive to maintain on the battlefield or off. As for the commercial implications of all of this, Fallows has provided an apocryphal anecdote in the words of a retired Air Force colonel:

> During the time when Curtis LeMay was the Air Force chief, there was a big movement to develop the Air Force flashlight. Flashlights never work, so they decided to develop their own...Well, people started thinking about all the extra things it should do. Somebody said, wouldn't it be great if it were a signal flashlight, so you could use it to send messages in code. And if it had a red light along with the white, so you could read maps at night and protect your night vision. And there were the usual military specs about performing after two weeks on the North Pole, or in the Sahara. Finally, it became the Tri-Command Flashlight: the Strategic Air Command, the Tactical Air Command, and the Air Defense Command all added their requirements. By that time, the thing was so huge you couldn't fit it in your flight suit...

---

84. Michael Boretsky, "Trends in U.S. Technology: A Political Economist's View," American Scientist, January 1975. Cited in Melman, Profits Without Production, op. cit., page 178.
85. quoted in Mosely, op. cit., page 82, from Mary Kaldor, "The Role of Military Technology in Industrial Development," Report to the Group of Government Experts on the Relationship between Disarmament and Development (New York, 1980) manuscript.
86. quoted in Ronald Miller and David Sawers, The Technical Development of Modern Aviation (London: Routledge, Kegan, and Paul, 1968), cited in Kaldor, The Baroque Arsenal, page 88.

> General LeMay came out one time, saw one of them all wrapped up, and asked what it was...So they peeled the airtight wrapping off one of them, got out a new battery--and it just wouldn't work...Finally they got the third one to work, but that was the end of the Air Force flashlight. Most pilots use the $1.50 Japanese plug-in model now.87

Direct Subsidies for R&D. Defense-related research and development expenditures remain the federal government's primary mechanism for influencing the direction of technological development in the United States. Before shooting up to around 70 percent in 1985, Pentagon R&D accounted for an average of about 50 percent of all federal R&D after the end of the Vietnam War, down from an average of about 60 percent between 1960 and 1973. Space research, at least 20 percent of which is defense-related, accounted for about 17 percent of all federal R&D between 1960 and 1973 and 14.3 percent after 1973. In addition, the military has continued to employ about 30 percent of the nation's scientists and engineers.88 Most federal R&D funding is provided directly to contracting firms during the life of a particular project, but the government also helps to support large national research centers which would be too expensive for commercial firms to operate on their own. In addition, the Pentagon typically funds all general overhead associated with private R&D undertaken by companies under contract for specific military projects.

Applied R&D. The hyper-sophistication of military technology flows, as Kaldor noted, from a tendency toward product specificity in defense-sponsored research and development. In fact, the U.S. Department of Commerce once estimated that, while it took an average of 10 man-years of industrial R&D to produce a commercializable patent, it would take 1,000 man-years to produce an identical patent based on either in-house or contract R&D for NASA or the U.S. Department of Defense.89 Indeed, according to Kaldor, a Pentagon study claimed, as early as 1960, that "very few patents arose from government-funded R&D, and very few of these were used commercially. Likewise, Texas Instruments reported that between 1949 and 1959, only 5 of 112 patents awarded to the company were developed under government contract, although the government funded two-fifths of R&D

87. Fallows, op. cit., pages 50-51.
88. Figures cited in Mosely, op. cit., page 80.
89. Melman, Profits Without Production, op. cit., page 178.

spending. Further, only 2 of the 5 patents were used commercially."90

As Robert Solo wrote nearly 25 years ago in the Harvard Business Review:

> a considerable part of space and military R&D efforts are devoted (1) to the preparation of research proposals and other presentations; (2) to the design, engineering, and testing of prototype weapons, space instruments, and space vehicles; (3) to the delicate modifications of instruments, mechanisms, and materials in the unique variation required for unique tasks; and (4) to the planning, scheduling, and integration of component development into a complex space and weapons system. None of these are likely to have any general value or to be of conceivable relevance to the advance of the civilian technology.91

Little has changed in the intervening quarter-century. In 1985, when the Department of Defense was to spend over $32 billion on research, development, evaluation, and testing, only $861 million, or about 2 percent of the total, was to be spent for basic research that might be expected to further commercial as well as military technologies. Only $5.9 billion (less than 20 percent of the total) was slated to be spent for "technology base" and "advanced technology development," the budget categories which cover spending for generic development in areas with the greatest potential for producing commercial spinoffs: electronics, computer science, other information sciences, advanced materials, environmental research, research on lasers and particle beams. The bulk of defense-sponsored R&D is devoted to strategic programs--space defense systems, the MX missile, second-generation cruise missiles--and tactical programs--undersea surveillance systems, the C-X transport aircraft, a larger gun for the Army's M-1 tank.92

Over-Specialized Personnel. Besides its increasingly applied nature, military technology is also becoming more specialized in terms of its institutional concentration within a relatively few large defense firms and government

---

90. Kaldor, The Baroque Arsenal, op. cit., page 91.
91. Robert Solo, "Gearing Military R&D to Economic Growth," Harvard Business Review, November-December 1962, page 54. Cited in Mosely, op. cit., page 80.
92. "1986 R&D Budget: Prosperity for defense, pain for national labs," Physics Today, April 1985, pages 59-65.

research labs.93 This sort of institutional isolation from commercial trends--and the demands of civilian consumers--contributes to a widely-noted over-specialization of skills among military R&D personnel, a fact which would tend to diminish the chances for successful commercial diffusion--through an exchange of personnel--of innovations developed under military auspices. Combined with the higher salaries typical of defense work, salaries which accustom defense workers to higher standards of living, over-specialized skills make it difficult for military R&D personnel to transfer their talents to market-oriented research. Civilian managers are likely to be suspicious, in any case, of "those whose backgrounds have been cast in defense as lacking 'cost consciousness'," fearing "that engineers who have spent years designing for reliability-before-cost and managers who are attuned to efficiency within the compartmentalized environment of the classified facility cannot readily reorient themselves for the optimization of profits." In sum, "The skills of the ex-defense worker, though highly developed, may not be especially attractive or relevant to a prospective employer."94

What is more, the increasingly military nature of large campus research projects influences the training of the next generation of military and civilian research personnel, graduate students for whom research assistanceships provided roughly 60 percent of all federally-funded financial aid during the late 70's.95 In fact, the classroom training of science and engineering students may be seriously affected as universities re-structure their curricula to gain access to military research funds and to reflect the military-oriented nature of the nation's highest paying research jobs. As Lloyd Dumas has found:

> Since military R&D tends to be far less cost-sensitive than civilian market-oriented R&D, courses in the cost implications of design and on the economic evaluation of technological projects will be de-emphasized. As an illustration, at the School of Engineering and Applied Science of Columbia University, there is such a course entitled "Engineering Economy." In the 1940's, it was a required course for all engineering undergraduates. By the 1970's, not only had it been removed from the list of requirements, but students were often discouraged from taking it by many faculty who considered it "unserious."96

---

93. Gansler, op. cit., pages 107-8.
94. Warren F. Davis, "The Pentagon and the Scientist," in Tirman, ed., op. cit., page 169.
95. Lloyd Dumas, in Tirman, op. cit., page 132.
96. ibid.

It is not surprising, in this context, that the United States' greatest high tech labor shortage, relative to the Japanese, is not thought generally to be a quantitative shortage at all, but rather a qualitative shortage, a shortage of talented R&D personnel skilled in "mundane, grubby engineering--the designing of a product so that it will meet given specifications, cost less to produce, use a minimum of critical materials in short supply, be reliable in performance and require reasonable maintenance in the hands of a customer."97 Indeed, to the extent that there are U.S. engineers who enter the job market with skills oriented to commercial needs, there is some danger that they will not have been educated in the nation's best-equipped schools: in 1980, for example, 56 percent of the Pentagon's support for institutions of higher learning went to just 10 elite universities.98

Diffusion. Pentagon-sponsored R&D has provided many of the nation's best electrical engineers with knowledge, training, and experience they have used later in solving technical problems for the commercial sector. Furthermore, "footloose" scientists and engineers weaned on the development of military hardware have served as conduits for the commercial diffusion of their own technological innovations by leaving defense contractors to start their own companies. Thus was integrated circuit development spurred by research into missile guidance systems. Charge-coupled devices and surface acoustic-wave technology, as well as a range of signal processing techniques with broad commercial applications, evolved from military requirements for satellite-tracking radar. Pentagon research led to the development of such commercially-successful computer applications as time-sharing, networking, and graphics; military communications needs spawned compact, mobile terminals, and pioneered the development of civilian satellite communications. Pentagon-supported R&D also provided a forum for the development of concepts and components crucial to further progress in radio and radar astronomy, microwave spectroscopy, and a wide range of instrumentation used in meteorology, geology, and health care.

---

97. Simon Ramo, America's Technology Slip (New York: John Wiley and Sons, 1980). Ramo is one of the founders of TRW.
98. Calculated by Lloyd Dumas from data in National Science Foundation, Survey of Science Resources Series, Federal Support to Universities, Colleges, and Selected Non-Profit Institutions, Fiscal Year 1980 (Washington, D.C.: U.S. Government Printing Office, 1982) Table B-16, pages 41-42. From Dumas, in Tirman, ed., op. cit., page 132.

Likewise, research scientists and engineers have helped to diffuse defense-sponsored innovations throughout the aircraft industry, though in this case the pattern seems to be one of diffusion within multiproduct corporations that have established civilian-oriented divisions responsible for adapting military technologies to commercial products. Even before the Second World War, technology transfers from the military to the civilian aircraft sector included such significant innovations as radial air-cooled engines, retractable landing gear, two-way radio communications, the turbo supercharger, and high-octane fuels. Since the war, spinoffs have included the turbojet engine, swept-back wings, adhesive bonding, titanium alloys, and both heavy-press and numerically-controlled machine tools.99 Development of the B-47 and B-52 bombers led directly to the popular Boeing 707; the Douglas DC-8 aircraft evolved from the A-3D, A-4D, and B-66 military aircraft. Boeing's 747 is based on design work done for the company's unsuccessful bid to build the C-5 cargo plane.100 According to a government study released in 1972, 70 percent of the technological advances made in aviation since 1925 had their origins in military-sponsored research.101

It should be emphasized, as well, that the military market itself enabled U.S. aircraft manufacturers to gain enormous economics of scale in production operations that could be used for building both military and civilian aircraft. By providing not only substantial direct subsidies for R&D, but also long production runs and stable profits, the Pentagon enhanced the industry's existing competitive advantages--including a large domestic market--by insisting through state-of-the-art performance specifications in its procurement contracts that aircraft manufacturers remain at the technological forefront.

Restrictions on Diffusion. Even when new technologies developed by military research personnel happen to exhibit a strong potential for commercial application, the spectre of export and publication controls can stop commercial spinoffs dead in the water. The Pentagon is currently increasing, from 13 to 20 percent, that part of its research and development budget whose very object is a secret--Defense officials will not publicly disclose what they are funding. The Secretary of Defense can already forbid publication of roughly one-fifth of the un-classified research performed by Pentagon contractors.102 In one famous case, in 1982, government officials summarily withdrew nearly 150

99. Magaziner and Reich, op. cit., pages 231-32.
100. ibid. page 232 and Gordon, National Journal, op. cit., 1983.
101. ibid.
102. Robert B. Reich, New York Times, May 29, 1985, op. cit., page 27..

unclassified scientific papers from presentation at an international academic conference whose participants included scientists from the Soviet bloc.103

The Pentagon has also insisted on the right to review academic work before it is published, and it routinely includes pre-publication review clauses in its research contracts. But such restrictions on the free exchange of scientific information carry within them the potential for severe damage to the nation's ability to generate and commercialize technological innovation. Even Edward Teller, inventor of the hydrogen bomb and certainly no enemy of the Pentagon, has written that:

> Science thrives on openness--researchers should, and often must, share their findings...Rapid progress cannot be reconciled with central control and secrecy. The limitations we impose on ourselves by restricting information are far greater than any advantage others could gain by copying our ideas...Adopting a policy of openness...would strengthen our relationships with our allies as well as illustrate the advantages of freedom to our Soviet colleagues.104

In terms of strengthening our relationships with our allies, we should keep in mind, also, that a proliferation of export-controls on dual-use technologies might tear the intricate web of trading arrangements which currently help U.S. manufacturing firms to gain access to world markets. According to Borrus and Zysman, the possible consequences of over-zealous U.S. export controls include reinforced European and Japanese efforts to develop indigenous technological capabilities, shutting American firms out. Moreover, they may encourage foreign firms to look to each other as technology sources rather than to U.S. firms. They may lead foreign manufacturers, when it is practicable, to

---

103. Ross Gelbspan, "When Scientists Get Aid from the U.S.," The Boston Globe, January 23, 1984, page 1. Cited in Dumas, in Tirman, ed., op. cit., page 166. This incident occurred during the August 1982 conference of the Society of Photo-Optical Instrumentation Engineers, whose acronym, unfortunately, is SPIE, in San Diego, California.
104. Edward Teller, "Secrecy: The Road to Nowhere," Technology Review (October 1981), cited by Dumas, in Tirman, ed., op. cit., pages 127-28. See also Stephen H. Unger, "National Security and the Free Flow of Technical Information," Committee on Scientific Freedom and Responsibility, American Association for the Advancement of Science (AAAS), September 1981.

design U.S. components and equipment out of future systems, lest they become too dependent on "unreliable" American suppliers. Not only could these actions freeze the United States out of expanding markets in the short run; they could also undermine long-run commercial competitiveness by denying American firms the merchandizing experience they need to tailor their wares successfully to the needs of foreign consumers.105

Summary. To review, a central task of the internationally competitive high tech firm is to develop a flexible organizational structure which allows it to identify shifting customer needs and to adjust its range of products and production techniques quickly in response to those changes. To ensure that there will be internal resources available for continued innovation, effective product development processes designed to meet varied and changing customer needs must then fit into a coherent market strategy aimed at establishing a sustainable market position in international competition. We have identified two generic strategies--the technology leader and the technology follower--arguing that, although most firms will tend to pursue one strategy more than the other, most will pursue some combination of both.

Nevertheless, to paraphrase Zysman again, the firm's strategy and thus its structure and the organization of its day-to-day routine reflects not only the dictates of industrial efficiency and profit maximization, but also the firm's institutional and political setting. When there is a major change in that setting, as when a commercially-oriented firm becomes relatively more dependent on the Pentagon for resources vital to its continued existence, choices made by the firm in response to the changed nature of its institutional relationships and the shifting patterns of the tasks it must perform to survive can provoke changes in routine organizational behavior. These choices and those changes will be determined, to a large extent, by the structure of the dominant institution, in this case, the Pentagon, because the firm must reorganize itself in a way which facilitates access to routes of influence on decision-making in the dominant organization.

In an overtly protectionist environment, practices which might otherwise be expected to promote competitiveness--state-of-the-art procurement, direct subsidies for R&D, diffusion through personnel, volume production, price premiums, "buy American" provisions--can shade easily, almost imperceptibly, into threats to the competitive performance of contracting firms--technical

105. Borrus and Zysman, Datamation, op. cit., pages 187-91.

over-sophistication, applied R&D, over-specialized personnel, restrictions on diffusion in the name of national security, pork-barrel procurement, sole-sourcing, cost-plus contracts, damaging insulation from competitive pressures to innovate.

Thus, the increased importance of Pentagon contracts to the financial health of America's high tech industries threatens to undermine, from within, the U.S. competitive position in a range of market-dominated high tech sectors. It is to this current threat that we turn last, as we apply our set of guiding questions to two major military research initiatives in microelectronics and advanced computing.

IV. The Story in Progress: Current Programs

VHSIC. Although some have described the VHSIC program as an effort by the American government to subsidize U.S. semiconductor producers in response to conspicuously successful Japanese efforts along the same lines, the program is best viewed not as a self-conscious attempt by the Pentagon to once again lead the market, but as an attempt by the military to catch up to commercial technology and to harness any further technological advances to its own purposes.106

As noted earlier, the volume production that enabled integrated circuits to compete in the commercial marketplace with discrete components emerged, initially, out of the Pentagon's development of the Minuteman ICBM in the mid-1960's. As a result, perhaps ironically, defense contractors were no longer the semiconductor industry's primary customers by the early 70's. Indeed, as technological advances moved defense contractors toward increasingly complex and expensive-to-design chips, custom-tailored to military specifications, military and commercial needs diverged even further. A new microprocessor could require more than a year of design work, at a cost exceeding one million dollars. Commercial semiconductor producers understandably preferred to focus their financial and design resources on commodity chips more likely to command lucrative large markets, such as those used in personal computers and video games.107

Defense contractors continued to provide an important market for domestic semiconductor manufacturers, as many advanced weapons systems could exploit the number-crunching capabilities of micro-circuits developed for commercial uses.108 Nevertheless, by the late 1970's, Pentagon purchases accounted for less than 10 percent of U.S. semiconductor sales, in marked contrast to the military's 90

---

106. this section draws heavily on the study by Leslie Brueckner, with Michael Borrus, "Assessing the Commercial Impact of the VHSIC (Very High Speed Integrated Circuit) Program" BRIE Working Paper #5, Berkeley Roundtable on the International Economy (BRIE), University of California, Berkeley, November 1984.
107. see Borrus, Millstein, and Zysman, op. cit., for a fuller discussion of the evolution of the market for semiconductors.
108. see Ken Julian, "Defense Program Pushes Microchip Frontiers," High Technology, May 1985, pages 49-57, especially pages 52-53, "The road that led to VHSIC."

percent share two decades earlier.[109] At the same time, Pentagon strategists were seeking to counter the newly-perceived quantitative superiority of the Soviet Union's nuclear arsenal with the development of qualitatively superior "smart" weapons incorporating state-of-the-art micro-circuitry. Defense contractors became increasingly frustrated over their inability to convince commercial semiconductor producers to develop custom chips for defense applications. "We were forced to use decade-old microelectronic technology," complained one Pentagon official, "while Atari games were using the latest."[110]

Defense contractors responded to this dilemma, initially, by developing their own semiconductor design and fabrication facilities in-house, a response that made the VHSIC program feasible when it began in 1980. In designing the program, Pentagon strategists maintained their traditional preference for awarding contracts to established defense system suppliers accustomed to the bureaucratic and technological esoterica of military systems development. Recognizing, however, that commercial technology was out in front, and desirous of engendering a substantial commercial response to the program, Pentagon officials designed VHSIC to encourage the teaming of traditional defense prime contractors with merchant semiconductor firms.

Though VHSIC includes a concurrent Phase III focused on generic research into processing and design technologies and conducted by universities as well as private corporations, the overall emphasis of VHSIC's Phases I and II is on product development and the rapid insertion of new technology into military systems. The program thus directs resources to the development of advanced chips <u>customized for specific defense applications</u>. By combining chip design and system design at the outset, the program's designers have found a way to sustain a constant focus on the military systems application of state-of-the-art VHSIC components while cutting the lag time (typically 10-15 years) between commercial chip development and military application.

At first glance, VHSIC seems ideally suited to generate commercially-significant technological breakthroughs.[111] Indeed, many firms have participated in the program precisely because they expect that VHSIC will push the pace of technological development faster than the private sector alone would be able to afford. Anticipated advances in the areas of VHSIC design and processing would be applicable, if diffused, to the design and fabrication of both custom and commodity VLSI (very-large-scale-integration) components. By encouraging the development of a range of processing

---

109. *ibid.*, page 52.
110. quoted in *ibid.*, page 52.
111. see Brueckner, *op. cit.*, pages 20-43.

techniques for VLSI circuitry, the VHSIC effort could serve as a testing ground for a processing technology conducive to the density and complexity of VLSI chips.

The program's emphasis on new lithographic and computer-aided design (CAD) techniques seems similarly suited to the strategic needs of U.S. producers, since it will have the effect of "shifting some of the design burden from the device manufacturer to the user, [thus allowing] semiconductor companies to reduce the amount of engineering time they must commit to new product development."112 In addition, the close interaction between defense systems suppliers and semiconductor firms in the design of VHSIC components will provide invaluable experience which could lead to the development of new manufacturing strategies for custom and semi-custom components. Such strategies are essential for bringing the cost of low-volume, custom-chip production down to a commercially-viable level.

A closer look at VHSIC reveals, however, that the program is likely to serve military needs at the expense of commercial development.113 For example, in order to fulfill military requirements, five of the six Phase I teams developed custom, rather than standard, programmable chips which could have been adapted to a variety of military and commercial systems and which would have been more suited to low cost, mass production.114 Significantly, only Texas Instruments, which combined its own systems and semiconductor divisions to form a single VHSIC team, pursued the standard, programmable option. TI is the only team leader whose primary business is semiconductors. It was not among those teams awarded one of three Phase II contracts in October 1984, for reasons that remain unclear, since the Pentagon did not publicly disclose its criteria for selection.115

As for those teams which took the custom design route, military requirements again skewed technological choices away from paths most relevant to commercial needs. For example, VHSIC contractors have met the Pentagon's goals of minimizing turnaround time between technology development and insertion into final systems by choosing design tools which do not maximize utilization of the chip's surface. For profit-seeking commercial firms, however, cost is

---

112. "Semiconductor Industry Supports Defense Plan," Aviation Week and Space Technology, February 16, 1981. Quoted in Brueckner, op. cit., page 29.
113. Brueckner, op. cit., pages 44-82.
114. The six teams were: Honeywell, Hughes Aircraft (teamed with Signetics), IBM, Texas Instruments, TRW Systems (with Motorola), and Westinghouse (with National Semiconductor).
115. The Phase II "winners" are IBM, TRW, and Honeywell. see Julian, High Technology, op. cit., page 53.

directly related to circuit-density per chip; the VHSIC program deflected these firms from seeking high density designs that would pay off over long production runs.116

Efficient use of the chip's "real estate" may be less important for custom applications, where the number of custom designs available from a firm may be the crucial competitive variable. But, in that case, VHSIC can have positive commercial effects only if computer-aided design tools developed by the military are characterized by open architectures that can be quickly and flexibly adapted to civilian uses. Quick turnaround technology is certainly important, but even dramatic improvements in military turnaround times (say from seven down to two years) are nowhere near the speeds required by custom chip producers in the commercial marketplace.

Even with VHSIC, incidentally, some industry insiders claim that the rate of technology insertion into military systems has not increased by much.117 Some reports indicate that merchant semiconductor producers have tried to reduce the delay between the design of commercial and military chips by manufacturing their commercial chips to military standards, but the view most widely shared throughout the industry is that the Pentagon's emphasis on testing and re-testing is needlessly costly and technically obsolete. Military specifications emphasize the screening out of bad chips after they are built, whereas the industry today has adopted the Japanese-inspired practice of building quality assurance into the production process, that is, manufacturing fewer bad chips to begin with. The military quality assurance system has begun to crumble despite Pentagon requirements, because U.S. commercial firms have had to face a strong competitor with a fundamentally different manufacturing philosophy.118

Nevertheless, the process of getting a chip approved for military use still takes so long and requires so much bureaucratic red tape that the chips slated for use in a weapons system are often obsolete by the time the system makes it from design to production. Military screening often takes more than a year and is responsible, by some accounts, for over half the cost of a typical military-qualified chip. The long lag time encourages defense system suppliers to resort to source control drawings (SCD's), a long list of specifications for manufacture and testing which enable contractors to avoid the hassle and expense of getting commercial or dual-use devices approved for military use. Ironically, this has led to a situation in which a

---

116. see Brueckner, op. cit., pages 47-48.
117. see Andrew C. Revkin, "A War Over Military Chips," Science Digest, July 1985, pages 56-79.
118. ibid., page 56.

specification system designed to standardize the industry has in fact encouraged the proliferation of costly non-standard chips.119 The explosion of SCD's impedes quality control efforts as chip producers are overwhelmed with "thousands of separate specifications of devices that are in many cases identical...[The system] produces extremely expensive products that at best are only equal to their commercial, off-the-shelf counterparts and in some cases are worse."120

In addition to imposing technological and testing requirements with adverse implications for commercial competitiveness, the Defense Department has joined the Commerce Department in attempts to prevent VHSIC technology from reaching the Soviet bloc. Restrictions have been placed on discussion in open (non-classified) technical symposia of either the architectures or performance characteristics of contractors' chips; manufacturers may not discuss details of the software used in either their CAD or fabrication processes. Current Pentagon restrictions are so stringent, in fact, that VHSIC contractors are forbidden even to publish close-up, front-foward photographs of their chips. One story has it that, when the General Accounting Office insisted on such photos for an unclassified report on the program, VHSIC officials were directed to send, instead, an aerial photograph of a parking lot, reduced in size until the cars resembled a cluster of micro-circuitry.121

In the meantime, the fear that export and publication restrictions might spill over onto their commercial operations has led VHSIC contractors to isolate their military programs from their internally-funded commercial R&D. For example, Brueckner interviewed the manager of the commercial LSI division of a large VHSIC prime contractor who "indicated that he keeps `copious files' detailing the complete abyss between VHSIC and VLSI research" even though the firm's commercial signal processing components were "extremely similar" to VHSIC circuits. The manager indicated that the company was pursuing parallel research efforts in order not to subject commercial research and products to DOD publication and export controls.122 Industry officials continue to argue, nevertheless, that VHSIC technology will find its way inevitably into commercial semiconductor products: "If we are using improved fabrication techniques in one part of our manufacturing facilities to produce VHSIC devices, and these techniques are sorely needed in our commercial device facility to meet Japanese competition, then the VHSIC technology will

---

119. ibid.
120. ibid.
121. Julian, High Technology, op. cit., page 57.
122. Brueckner, op. cit., page 73.

'diffuse' into our commercial operations in spite of Pentagon-imposed barriers."123

It is too soon, of course, to arrive at a definitive characterization of the commercial implications of VHSIC; indeed, it is the nature of the subject that no such characterization is ever likely to be universally accepted. By applying our guiding questions to the case, however, and framing them in the light of our previous discussion of the pros and cons of Pentagon involvement from a commercial standpoint, we can already discern some troubling signs.

For instance, although the program is clearly designed to advance the state-of-the-art of component technology, the effort is also constructed to focus manufacturers' attention on the development of chips customized for specific military applications. Although anticipated advances in VHSIC design and processing techniques--including an emphasis on new lithographic and computer-aided design processes--clearly match the current needs of commercial producers, there are signs that the government intends to prevent such advances from diffusing readily into commercial applications--at home or abroad. Indeed, strict export and publication controls are leading some manufacturers to pursue costly dual-development strategies, while their foreign competitors are able to focus all of their resources in a unitary effort.

The phased bidding process appears to promote competitive technology development and efficient manufacture, particularly by teaming systems houses with merchant semiconductor firms, but again, military officials seem to be rewarding only teams who focus their efforts toward specific military applications. They did not, for example, pursue Texas Instruments' standard, programmable chip design, which would seem to lend itself more readily to lower-cost, volume production. Indeed, the Defense Department has reinserted itself into the semiconductor industry at a time when that industry has already developed a well-established technological trajectory, backed by a large (some would argue over-large) stock of sunk investment; yet, it has done so precisely because military and commercial technological priorities are thought to have so widely <u>diverged</u> over the past decade. The merchant semiconductor firms participating in the program are the source, historically, of much of the energy and innovation that shot the U.S. industry to the top during the 60's and early 70's; yet their growing dependence on Pentagon funding, aggravated by a slumping chip market in recent years, turns their attention away from commercial priorities and threatens to inhibit the diffusion of any commercially-applicable innovations they <u>do</u> produce. All of this, most critically, in the face of on-going efforts by foreign

---

123. quoted in Julian, <u>High Technology</u>, <u>op</u>. <u>cit</u>., page 57.

governments, particularly the Japanese, to promote the production of commercial VHSIC components within the same time frame as the U.S. military program.

Perhaps a good part of the problem here is that, as with the development of numerically-controlled machine tools in the early 50's, the Pentagon is dealing now with a mature industry whose production apparatus is already targeted toward its own well-defined set of commercial priorities. In that case, we must look also at a newer technology, one closer to the generic stage of development that characterized semiconductor components when the Defense Department first became involved with them in the late 1950's. We turn, then, to a brief discussion of the Pentagon's current interest in the development of supercomputers and artificial intelligence.

The Strategic Computing Initiative. It is too early, of course to assess the competitive impact of the Pentagon's Strategic Computing Initiative (SCI), particularly on the growing, but still fairly limited commercial markets for supercomputers and artificial intelligence software. There are indications, however, that SCI's designers at the Defense Advanced Research Projects Agency (DARPA) have adopted one of VHSIC's more troublesome features, from a commercial standpoint--a developmental strategy that involves embedding generic technologies directly into military systems.

If any Defense agency must play a major role in promoting the long-term commercial interests of advanced computing in the U.S., then DARPA is the perfect one to play it. With a budget in fiscal year 1985 of approximately $714 million and a staff of 150, DARPA could hardly be more different from the rest of the defense research establishment. Its directors have been among the world's top scientists, its staff and bureaucracy are relatively small and uncharacteristically flexible, its research focus is not on the design of particular weapons systems, but on the pursuit of revolutionary, long-term advances.124

Through its Information Processing Techniques Office (IPTO), for example, DARPA has played a pivotal role in pioneering the computer-related technological advances which underly such commercially-successful applications as timesharing, networking, and graphics. Indeed, SCI's defenders often stress DARPA's historic role in shaping U.S. leadership in the computer field, noting especially the agency's early emphasis on interactive computing for command

---

124. see James Botkin and Dan Dimancescu, "The DARPA Exception," in Tirman, ed., op. cit., pages 222-25; and Dwight B. Davis, "Assessing the Strategic Computing Initiative," High Technology, April 1985, pages 41-49.

and control--which led to the development of timesharing--and its subsequent interest in computer networking, which led to the development of ARPANET, the nationwide packet-switched computer network that has served as an important research tool for computer scientists while at the same time expanding the horizons of data communications technology.125

What worries many computer scientists about the Strategic Computing Initiative is that the heavily applied nature of the program seems to represent a sharp departure from DARPA's proven model for success. Similar to the model devised earlier for the Pentagon's VHSIC effort, DARPA has decided to pursue generic research and military product development simultaneously; that is, DARPA intends to demonstrate the utility of the generic technologies it develops by designing them at the outset into three prototype military systems--an autonomous land vehicle for the Army, a pilot's associate for the Air Force, and a battle management system for the Navy. Each of these prototypes has one basic characteristic in common: each is projected to work by processing "knowledge," by "thinking" for itself, instead of merely processing raw numeric data. Thus each system will depend heavily on the further development of artificial intelligence (AI) software, expert systems, machine vision, speech recognition, natural language processing, and the development of parallel processing computer architectures.126

Many supercomputer proponents are concerned about the program's heavy emphasis on artificial intelligence, a consequence of the military's ambitious prototype goals. Indeed, DARPA's interest in developing superspeed computers seems to be primarily a by-product of its interest in AI. SCI's computer architecture program resembles VHSIC's program for the development of superspeed chips, in that it funds several simultaneous projects in the same area. The system spurs creative competition between research groups and provides some insurance against the possible failure of individual approaches; it allows DARPA to play the role of venture capitalist, picking winners and losers from among the best in the field.127 The concern, again, is with the competition's pre-set focus on developing technologies designed to work in particular military systems. Nevertheless, some in the computer field are quite sanguine

---

125. Davis, High Technology, op. cit.
126. see Willie Schatz and John W. Verity, "Weighing DARPA's AI Plans," Datamation, August 1, 1984, pages 34-43; and Schatz and Verity, "DARPA's Big Push in AI," Datamation, February 1984, pages 48-50.
127. Davis, High Technology, op. cit., page 43; and Dwight B. Davis, "Super Computers: A Strategic Imperative?" High Technology, May 1984, pages 44-52. Hereafter referred to as "Super Computers."

about the prospects for substantial overlap between advances in AI and superspeed computing. "There are some people who are jealous of the large amount of money DARPA is spending on artificial intelligence supercomputing to the exclusion of scientific supercomputing," says Burton J. Smith, vice president in charge of R&D at Denelcor, one of the three U.S. supercomputer manufacturers. But, he adds, "I think the artificial intelligence work will prove very beneficial to superspeed computing and vice versa."128

Regardless of their position on the relevance of AI research to supercomputing, many computer scientists assert that the country's interests would be better served if more computer research were funded through non-military sources. They claim that military requirements aim the trajectory of technological development away from research directions most likely to be relevant to the needs of commercial users. "Most AI people build a system acquiring knowledge scaled to a specific topic," notes David Waltz, professor of electrical and computer engineering at the University of Illinois. "To get funded they almost have to choose something of military relevance."129 In fact, the redirection of research (and, hence, technological development) can be quite subtle. In the words of J.C.R. Licklider, a former DARPA administrator now teaching computer science at MIT, "There are many choice points one passes in traveling through research, and if there's just a little shading and biasing of one to the right or to the left, you wind up in a pretty different place after you go through 1000 more choice points."130 Adds Abbe Mowshowitz, of the Renssalaer Polytechnic Institute, "People tend to

---

128. quoted in Davis, "Super Computers," op. cit., page 47. The other U.S. supercomputer manufacturers are Cray and ETA Systems, a spinoff of Control Data Corporation. See also, U.S. Congress, Office of Technology Assessment, Information Technology R&D: Critical Trends and Issues (Washington, D.C.: U.S. Government Printing Office, February 1985) pages 57-62; and Richard Corrigan, "The Latest Target of the Japanese--U.S. Preeminence in Supercomputers" National Journal, April 2, 1983, pages 688-92; and Nancy R. Miller, "Supercomputers" CRS Review, March 1984 (Congressional Research Service) pages 17-19; and "Supercomputing: Number-crunching for research" Physics Today, May 1985, pages 51-53; and "Advanced Computing: The Commercial Impact of Japanese Programs on U.S. Competitiveness," briefing materials for a BRIE seminar on advanced computing, Berkeley Roundtable in the International Economy (BRIE), University of California, Berkeley, June 27, 1984.
129. quoted in Datamation, op. cit., August 1, 1984, page 42.
130. quoted in Davis, High Technology, April 1985, op. cit., page 46

police themselves when competing for funds. They make choices on the range of problems they'll tackle."131

This sort of self-policing by researchers could have an important long-term effect on the training and proclivities of America's small AI community. In the three sub-fields of artificial intelligence likely to produce the most applications in both military and commercial environments--expert systems, machine vision, and natural language processing--there are approximately 60 faculty at the nation's top universities, turning out roughly 30 Ph.D. graduates each year, of whom about half take jobs in private industry.132 Since SCI is expected to quadruple the federal funding previously available for R&D in artificial intelligence and related hardware, more and more faculty researchers and graduate research assistants will be focusing their efforts toward military applications. Other applied research, such as work on computer-assisted education and "intelligent library" systems--may fall by the wayside.133 This is ironic, given the view so widely held in the U.S. computer industry that SCI will help Americans reach the Fifth Generation before Japan has left the Fourth. For Japan's efforts in artificial intelligence and supercomputing are focused explicitly on the enhancement of business and consumer productivity and on the improvement of social services, a far cry from the emphases of the Strategic Computing Initiative.134

Observers of the Pentagon's growing role in funding basic and applied research into advanced computing worry, also, that commercially-viable spinoffs will be subject to classification and thus restricted to military use. Although DARPA officials admit that some applied research may be classified, they contend that the bulk of SCI's generic research will not be. The program is set up so that most of the generic research will be done in universities; advanced computer architectures will be developed jointly by universities and private firms, and applied product development will mostly take place in private industry. It would seem, however, that DARPA's strategy of proving the viability of new generic technologies by embedding them in classified military systems could subject the technologies, themselves, to early classification. Even the program's most optimistic supporters recognize the danger to commercial spinoffs of an overemphasis on security. "The

---

131. quoted in Datamation, August 1, 1984, op. cit., page 42.
132. U.S. Congress, Office of Technology Assessment, Information Technology R&D..., op. cit., page 96.
133. ibid. Funds will quadruple from approximately $30 million to about $120 million, averaging the projected $600 million budget over its five-year lifetime.
134. Datamation, August 1, 1984, op. cit, page 42.

source of research won't be a problem," says Charles Zraket, whose non-profit MITRE Corporation does research for the Air Force. "...All the results of a generic nature will be completely useful in the civilian economy...The only drawback is if DOD puts this under such scrutiny that it doesn't allow results to be published. If tight security is clamped on this it won't attract the best people."135 Adds Republican Congressman Ed Zschau, who respresents the Silicon Valley, "We may find that the technology gets bottled up inside the military establishment. My concern is that specific technological breakthroughs--other than what's in people's heads--may be classified because they're considered to have military significance and therefore may be difficult to get out into the private sector."136

Once again, it is difficult to tell, while a program is in progress, whether its ultimate effects will be positive or negative on developments in the commercial sector. Like VHSIC, however, the Strategic Computing Initiative exhibits some qualities that are uncomfortably close to replicating the patterns that prevailed during the development of numerical controls by the U.S. Air Force. In this case, the Pentagon is dealing with a set of new technologies whose military and commercial potential is still only vaguely defined; the Pentagon is therefore interested in advancing the technological state-of-the-art, but it has attempted to yoke such advances to the requirements of specific military systems--an autonomous land vehicle, a pilot's associate, and a naval battle management system. Indeed, the Pentagon is engaged in creating both a market and a set of suppliers; it is contracting with both established universities and innovative, small firms; but the indundation of military funding is skewing the trajectory of technological development away from paths which might lead to lucrative commercial applications--paths being followed, with great determination, by foreign competitors. SCI is budgeted at about $600 million for its first five years; the Japanese are spending approximately $500 million on the ten-year Fifth Generation Project, plus another $200 million on a separate five-year Superspeed Computer Project. Aside from the problems of adapting over-specialized products and personnel to civilian uses, there is also a more explicit threat to the commercial diffusion of technological innovations in the form of strict export and publication controls. In sum, there are some early indications of the development of a military-dependent industry structure, isolated from the needs of potential commercial users. With so much military support flowing to the development of defense applications, the danger exists that promising commercial applications may die aborning from a lack of

---

135. quoted in ibid., page 42.
136. quoted in Datamation, February 1984, op. cit., page 50.

equivalent nurturing by the government or the private sector.

V. Conclusions and Concerns

Remote controls for television sets, solar-powered calculators, graphite tennis rackets--each of these consumer products is the direct result of aerospace technology developed for the military. Yet, all these products have at least one other important feature in common; the aerospace companies that developed them originally are not the companies that profit from selling them today. Indeed, the list is long of defense contractors that have failed to blend defense and commercial technologies successfully; Rockwell International and its Admiral T.V. sets, Grumman's flexible urban buses, Rohr's subway cars, Boering Vertol's trolley cars, McDonnell Douglas' jet-powered fire fighting platform.137 General Motors' recent acquisition of Hughes Aircraft has generated widespread skepticism among financial analysts and aerospace executives who have seen similar technology transfer strategies fail in the past. Although GM may eventually succeed with Hughes--developing, in the process, a computerized dashboard map system for highway navigation or a radar-based override system that can take control of the vehicle in road emergencies--the complete blending of such diverse corporate cultures is likely to take decades. Besides, the relevant test is not merely whether Hughes can contribute its technologies to GM's automotive products, but rather whether it can do so at an affordable price.138

Indeed, as we have seen, though military technologies can indeed be adapted to commercial uses, successful spinoffs are rare; most often they have occurred in sophisticated aerospace and electronics applications. In the first case, diffusion has been hastened by a basic similarity between the needs of military and commercial users; in the second, the route of diffusion was a product of historical happenstance: AT&T was afraid of premature classification as well as stepped-up anti-trust litigation, so it created a system through which technological

---

137. see Ralph Vartabedian, "Can Hughes Advance GM Car Building?" Los Angeles Times, June 23, 1985, Part V, page 1. For an interesting discussion of Boeing Vertol's attempt to provide trolley cars for Boston's subway system, see Melman, Profits Without Production, op. cit., pages 253-59. According to Melman, "the story of Boeing-Vertol's light-rail vehicle program in Boston is also the story of the Morgantown, West Virginia people mover; the BART system of San Francisco; the Washington D.C. subway; and the Grumman venture in city buses." ibid., page 259.
138. Los Angeles Times, June 23, 1985, op. cit.

innovations could be quickly licensed (hence diffused) from Bell Labs to commercial manufacturers. With deregulation, that route of diffusion is now effectively closed; as for aerospace, the military nature of much new aerospace design has contributed to the failure of U.S. aircraft manufacturers to develop an airplane suited to the fast-growing commuter airline market. "In a pattern reminiscent of the U.S. auto industry in the 1960's," writes Robert DeGrasse, "American manufacturers, including Beech, Cessna, and Piper, have failed to invest in the technology necessary to develop an aircraft that can compete effectively in that market. Consequently, America's commuter airlines are turning to Canadian, French, and Brazilian firms to fill their needs."139

In short, the aspects of military involvement which may serve to promote the development and commercial diffusion of products or production techniques based on new technologies--state-of-the-art procurement, direct subsidies for R&D, diffusion through personnel, volume production, price premiums, "buy American" provisions--cannot themselves substitute for a civilian industrial policy, especially in the face of determined, government-supported efforts by foreign competitors to advance the commercial state-of-the-art over the same time span as the U.S. military program. Indeed, even under the best circumstances, when outside factors ease the processes of commercial diffusion and adaptation of military-sponsored innovations, the positive aspects of military programs can easily turn into commercial impediments, as commercial producers--saddled with technical over-sophistication, applied R&D, over-specialized personnel, restrictions on diffusion in the name of national security, pork-barrel procurement, sole-sourcing, cost-plus contracting, and damaging protectionism--find themselves less and less able to compete in civilian markets and thus more dependent on the Pentagon for resources vital to their continued existence.

The creation of military-industrial firms, of a military-dependent and uncompetitive industry structure, is aided by military programs that focus on the development of specific military product applications instead of promoting the general technological state-of-the-art; that draw the attention of commercial producers away from the development of technological applications consistent with the commercial market requirements of the involved industry toward esoteric, over-sophisticated military applications; that rely on sole-source contracts and cost-plus, weapons-specific production technologies instead of promoting competitive product development and efficient, generalizable production technologies; that promote small-batch, "one-of-a-kind" custom production instead of mass production or

---

139. DeGrasse, in Tirman, ed., op. cit., page 83.

flexible specialization aimed at creating economies of scale and scope; that disrupt established technological trajectories and investment patterns in mature industries or that skew the technological development trajectory of brand-new industries by pointing them in a single, defense-oriented direction; that routinely reward established suppliers over small, innovative start-ups; that restrict the diffusion of military-sponsored advances through technological over-specialization or direct export and publication controls; and that do all or most of these things in the face of parallel, commercially-oriented R&D projects sponsored by foreign competitors and aimed explicitly at advancing the commercial state-of-the-art over the same time span as the military program.

We do not wish to argue, of course, that the military should never be involved in the development of advanced technologies, nor that America's commercial interests should in all cases be preferred to valid considerations of national security. A case can be made, however, that to the extent that the Defense Department's technological development policies are undermining U.S. competitiveness in high tech sectors, those policies are leading also to the gradual erosion of America's technological edge, a development which could ultimately leave the United States dependent on other nations for the continued technological superiority of its weapons systems. It would be ironic in the extreme if the Pentagon's response to the impression that U.S. military technology has lagged behind U.S. commercial technology in recent decades--an increased interest in involving commercial firms in its research and development efforts--ended up, instead, undermining the very organizational habits which enabled America's high tech sectors to be so innovative in the first place.

The link between the Pentagon's technological development policies and the nation's requirements for competitive industrial development must be made clear. The trade-offs between them must be made explicit. For in the absence of an explicitly commercial and, hence, <u>counterbalancing</u> industrial policy, military requirements can distort both the framework and the substance of American technological development, altering them in a way that leaves U.S. firms ill-suited for successful competition in world markets.