

CHAPTER 8

MILITARY PROCUREMENT AND COMMERCIAL TECHNOLOGY DEVELOPMENT IN A POST INDUSTRIAL ECONOMY

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CHAPTER 8

MILITARY PROCUREMENT AND COMMERCIAL TECHNOLOGY DEVELOPMENT IN A POST INDUSTRIAL SOCIETY

In an earlier book, *Technology, Growth and Development* (Ruttan 2001), I concluded that government sponsored research and technology development played an important role in the development of almost every general purpose technology in which the United States was internationally competitive. I gave relatively little explicit attention, however, to the role of military procurement in the development of commercial technology.¹

In this book I have reviewed the development of six general purpose technologies in which defense or defense related procurement has played a particularly important role in technology development. In each of these cases commercial development would have been substantially delayed without the stimulus from

¹ I am indebted to John Alic and to participants at a University of Minnesota Hubert H. Humphrey Institute of Public Affairs Freeman Center seminar on September 14, 2004 for comments on an earlier draft of this chapter.

military and defense related procurement. In one case, nuclear power, it is doubtful if the technology would have been developed at all in the absence of military procurement.²

In this book I do not argue, that the massive military and defense related R&D and procurement programs that I have reviewed in earlier chapters can be adequately evaluated in terms of their impact on commercial technology development. With rare exceptions benefit calculations have not been carried out. I do insist, however, that the American, and the global, technological landscape in which we live today would be vastly different in the absence of military and defense related contributions to commercial technology development.

In this final chapter I return to several issues that have emerged in the process of writing the earlier chapters. The *first* is the issue of technological maturity. The *second* is whether changes in the structure of the United States economy, and in the military

² In Appendix 1, I list the cortical dates in the development of the several general purpose technologies that I discuss in this book from the date of initial conception or invention through development for military and commercial applications. In Appendix 2, I construct a counterfactual history of the interrelated computer-microprocessor-internet technologies.

industrial base, preclude military procurement from continuing to play an important role as a source of new general purpose commercial technologies? The *third* is whether a major war, or threat of major war, is necessary to induce the United States to mobilize the research and development resources necessary to advance new general purpose technologies?

TECHNOLOGICAL MATURITY

A major deficiency in the induced, evolutionary and path dependency literature on technical innovation (Chapter 1) is an inadequate attention to the problem of technological maturity. After experiencing rapid or even explosive development along an initial trajectory, the older general purpose technologies, discussed in earlier chapters have often experienced a period of technological maturity or stagnation. In some cases renewed development has occurred along a new technological trajectory. In other cases alternative paths of technology development have not yet become apparent. In some cases, as in the electric power industry, measurable impact of a revolutionary new technology on economic growth has occurred only as the technology has approached technological maturity (David 1990).

There is a modest literature on innovation and product cycles.³ A formal model of the innovation cycle was first advanced by Robert Evenson and Yoav Kislev (1975). They traced the history of sugarcane technology development through three innovation cycles beginning in the middle of the 19th century. As each cycle reached maturity the productivity of research effort directed to the development of new technical varieties declined. In the first two cases, however, advances in basic biological knowledge opened up new opportunities for a new round of technology development.

A similar model was employed by Cowan and Foray in an analysis of the complementarities between military and commercial technology. They argued that when R&D is performed primarily with military applications in mind scientific and technical effort will be focused on identifying the part of the distribution that is most directly related to military application. When commercial applications are the primary focus technical effort will focus on development of the most profitable varieties. “Military and civilian R&D will explore different (though perhaps overlapping) parts of the technological distribution. This has a positive effect on the potential diversity that exists within any technology” (Cowan and Foray 1995: 861).

³ In the mid 1960s Raymond Vernon (1966) advanced a product cycle model to interpret the initial invention, modification and adoption of consumer durables in the United States (or other high income countries) and the later transfer of production to low wage economies as the technology matured. See also Grubler and Marquis (1969), Vernon (1979) and Ruttan (2001: 163-166).

Failure to advance along either the military or commercial part of the trajectory can, in their model, dampen technical advances in the other.

There is no implication that because an industry becomes mature and is no longer a dynamic source of growth in its country of origin that it can not continue to achieve modest output and productivity gains as it makes the transition from a leading to a sustaining sector. Similarly, as a result of international technology transfer, it may become a dynamic source of growth in less technically advanced countries. Mass production in the automobile industry achieved technological maturity in the United States by the late 1920's or early 1930s. It became a leading sector in several European countries and Japan during the 1950s. During the 1960s a series of technical and institutional innovations characterized as "just in time" and "total quality control" assembly were being implemented in Japan. By the 1970s they had begun to displace the traditional "Fordist" mass production system in the United States and other developed countries in automobile production (Ruttan 2001: 445-452; Chapter 2). Lower labor productivity in the production of wide bodied jets at Boeing than at Airbus in the early 2000s has been attributed to delay in moving beyond traditional mass production technology and organization at Boeing (**citation?**).

Aircraft propulsion is an example of a case in which a mature technological trajectory was followed rapidly by transition to a new technological trajectory. Piston-propeller aircraft propulsion achieved technological maturity in the late 1930s. A transition to a jet propulsion trajectory was well underway by the late 1940s. In the absence of military support for R&D during World War II and military procurement during the Korean War the transition to jet commercial aircraft propulsion would have occurred much more slowly (Chapter 3).

The technology of electric power generation from coal fired power plants reached technological maturity between the late 1950s and the early 1960s with boiler turbine units in the 1000 megawatt (MW) range⁴. The transition to nuclear energy as a primary source of electrical power has occurred much more slowly than anticipated. Political considerations contributed to the premature selection of the light water power technology for commercial development and led to a path dependent lock-in from which the U.S. commercial nuclear power industry has not yet been able to escape. The transition to a trajectory based on alternative energy sources (geothermal, solar, wind and biomass) remain uncertain. None of the

⁴ “The technical design frontier was limited by the ability of boilers to withstand high temperature and pressure. The frontier was pushed out by incremental advances, particularly in metallurgy, involving the development of high temperature alloys. Most of the shift to higher temperatures and to reheat cycles was completed in the 1948-57 decade with little change thereafter, whereas the increase in pressure rating continued until the 1960s” (Gordon, 2004:177).

technical alternatives, including nuclear power, promise sufficient cost reduction to enable the electric power industry to again become a leading rather than a sustaining sector in the U.S. economy Chapter 4).

In the late 1960s there were indications that mainframe computer development was approaching technological maturity. New trajectories were opened up by the development of the microprocessor. The minicomputer replaced the mainframe as the most rapidly growing segment of the computer industry and as an important source of output and productivity growth in the U.S. economy (Jorgenson 2001; Gordon 2004: 22-49).

Support by defense and space agencies contributed to advances in mainframe supercomputer speed and power into the early 1990's. But by the late 1990s substantial concern was being expressed about the sources of future advances in computer performance ((National Research Council 1999: 2003: Chapter 5).

It would be premature to characterize either the INTERNET (Chapter 6) or the space communication and earth observing industries (Chapter 7) as technologically mature. Both are, along with the computer and semiconductor industries, part of a rapidly evolving communications revolution that is expected to extend well into the first quarter of the 21st century. The collapse of the communication industry "bubble" beginning in

the late 1990s does, however suggest caution about some of the more extravagant expectations.

STRUCTURAL CHANGE

A second major issue is whether changes in the structure of the United States economy, and of the defense industries and the defense industrial base, preclude military and defense related R&D and procurement from continuing to play an important role in the generation of new general purpose technologies.⁵ This issue has been the source of a substantial defense policy debate. Should, for example, military procurement policy be more explicitly directed to enhancing commercial technology spinoffs or to the development of dual technologies.⁶

⁵ The defense industrial base includes the full range of industries that contribute importantly to the supply of products that make a unique or important contribution to the nation's defense capacity. The defense industry is a subset of the defense industrial base. It consists of firms that produce largely or entirely for the military market. Thus a firm in the steel industry that produces a specialized steel crucial for the production of submarines is part of the defense industrial base but not of the defense industry. In contrast, the missile and space vehicle industry, which sells 85 percent of its production to the military is part of the defense industry even though a small part of its production may be for civil uses (Flamm 2000: 60-64).

⁶ Drawing on Cowan and Foray (1995), I define spinoff (or spillover) as a situation in which research and/or technology development conducted entirely for application in one sector (military or commercial) is readily applied or adapted for use in the other sector. In contrast the term dual purpose is used to describe technologies that are specifically designed for use by, for example, both the military and the commercial sectors.

Spinoff

During the first two post World War II decades the spinoff issue attracted relatively little attention. It was generally taken as self evident that substantial spinoffs of commercial technology could be expected from military procurement and defense related R&D. It was also generally assumed that there was no need for policies to enhance the development of dual-use technology—technology developed with the specific objective of meeting both military and commercial demands.

“According to the prevailing view the nations pursuit of economic and military activity involved two separate spheres of technological activity. The first consisted of self-initiated actions by private firms aiming at profits and productivity in the market economy. The second effort, for national defense (and defense related missions) ... was exclusively public and relied on federal

funds to generate the technology needed by the Pentagon and other so-called mission agencies (Alic et al., 1992: 8-9).⁷

The slowdown in the rate of economic growth in the United States after the early 1970s generated considerable controversy about the role of the military in technology development.⁸ Some critics had argued, even in the 1960s, that defense related R&D was becoming a burden on economic growth. Military and space research was viewed as drawing scientific and technological capacity away from civilian applications. It was argued that the effect was to slow the advance of industrial technologies and reduce the rate of economic growth (Solo 1964: 49-60; Dumas 1980; Kaldor 1981; Lichtenberg 1984; 1989).

In addition defense industry firms, even those with substantial commercial activity, often failed to take advantage of

⁷ This “linear” view was articulated most forcefully in the influential report on post-war science policy, prepared at the request of President Roosevelt, under the direction of Vannevar Bush, *Science the Endless Frontier* (1995). As late as the mid-1980s the view was vigorously defended by George Keyworth, science advisor to President Reagan. Keyworth noted that the Regan administration had been successful in increasing the share of federal research support for basic research while reducing the share devoted to applied research, technology development and demonstration.(Keyworth 1984).

⁸ The rate of growth of labor productivity (output per hour worked) in the U.S. non-farm business economy declined from an annual rate of 3.5 percent in 1948-53 to 1.5 percent per year in 1973-95. It rose to 2.6 percent per year between 1996 and 2000 and to 4.0 percent between 2001 and 2004 (Bureau of the Census 1975; IP 2004). For an analysis of long term productivity growth rate in the U.S. see Jorgenson (2001) and Gordon 2004: 22-49).

technology transfer opportunities from their military R&D.

Weidenbaum has observed that “those defense firms that do operate in civilian markets tend to maintain operationally separated insulated divisions that have little contact with each other, merely reporting to the same top manager” (1992: 51).⁹

An effect of the productivity slowdown that began in the early 1970’s was to question the continuing relevance of the spinoff paradigm. The spinoff paradigm had emerged in an era “when the United States dominated world technology and national defense dominated United States technology development” (Alic et al., 1992: 25).

((Insert Box 8. about here))

One of the factors advanced to explain the apparent loss of relevance of the spinoff paradigm was the emergence of economies in Western Europe and East Asia, particularly Germany and Japan, as competitors of the United States in a number of high technology

⁹ I first became sensitive to this issue in late 1970’s when a student, then working for a Minneapolis based firm that was substantially engaged in both defense and commercial R&D, noted in a term paper that a wall of secrecy separated the firm’s military and commercial research. His interpretation was that the firm did not want its commercial division to be “contaminated” by the costly production processes involved in meeting defense related contracting, quality, regulatory and security requirements.

industries. Another was the revolution in military affairs associated with the winding down of the Cold War. Reduction of tensions between the United States and the USSR held out the promise, or at least the hope, for a dampening of the growth of military and defense related budgets. A third was an intellectual challenge to the linear model of the role of science in technology development (Fig. A3-1).

The linear model was deeply embedded in military procurement practice. Procurement followed a “pipeline” progression. The first step is the preliminary process of concept definition, which itself requires substantial R&D resources, conducted by the contracting agency. The second phase involves design, demonstration and validation. In this phase multiple firms may advance competing designs. The process then moves forward to full scale prototypes and final demonstration—a phase that absorbs up to 20 percent of total system acquisition cost. This phase may involve more than a single firm. The final phase involves selection of a sole source contractor and development of

the capacity for full production of the system. Numerous subcontractors will be involved in this stage. The demonstration-validation stage typically takes 3-4 years and the full scale development phase 4-5 years. The technology remains in production, on average, for about 15 years and in service for many more (Flamm 1999: 241; Rogerson 1944).¹⁰

By the mid 1980s this process was beginning to appear increasingly incongruent with R&D practice in the most advanced sectors of the commercial economy. The postwar United States economy had witnessed an accelerating transformation of the relationships among science, technology and production. It became widely recognized that commercial production processes pressed more immediately, and sometimes beyond, advances in scientific knowledge (Alic et al., 1992: 11-22).

¹⁰ For an excellent brief history and critique of the weapons procurement process see Lovell et al (2000: 15-18) Lovell et al note that most past efforts to reform the weapons procurement process have had the effect of introducing regulations and processes that have raised barriers to the transfer of technology between military and commercial applications (Lowell et al 2000: 15) For an exhaustive account of the evolution of military procurement policy and practice from the mid 1920s through World War II see Holley. For detailed analysis of the weapons acquisition process that still retain substantial currency see Scherer (1964) and Damhoff (1968). For economic approach to analysis of military procurement policy see Rogerson (1994a and 1994b) and Sandler and Hartley (1995).

Dual Use

Beginning in the mid 1980s and into the mid 1990s civil-military industrial base integration, usually referred to in terms of development of “dual use” military and commercial technology, became the conventional solution offered for how to solve the problems of rising cost and declining quality in post Cold War military procurement (Alic et al., 1992; Carnegie Commission 1993). Dual use was itself, of course, not new. Technology development in the several industries discussed in the earlier chapters of this book—in gun manufacture, aircraft, nuclear power, computers and semiconductors, and in the space industries—have been, at least in part, dual use.

Efforts to institutionalize dual use in the procurement process have been controversial. Advocates believed that there were extensive dual use opportunities in defense and commercial technologies, processes and practices and that DoD adoption of commercial acquisition practices could result in substantially lower

procurement costs. Critics were skeptical about the extent of potential overlap between commercial and military products and processes. They argued that a specialized cadre of defense related firms operating under close regulation and supervision remained the best solution for weapons procurement (Lorell et al 2000: 2-3).

In the mid 1980s concerns about the competitiveness of a number of high technology industries, semiconductors for example, led to a proposal that ARPA be given authority to undertake commercial technology initiatives under the rubric of “dual use”. In 1987 the Congress authorized a public-private Semiconductor Equipment Manufacturing Consortium (SEMITECH), in which the federal government proposed to contribute up to 50 percent of the cost over a 5-10 year period for development of new high technology equipment for the manufacture of semiconductors. In an influential book published in 1992, *Beyond Spinoff*, five highly respected students of defense industrial policy urged a much more conscious weighting of potential civilian applications in defense related research,

technology development, and procurement (Alic et al., 1992). An implication is that support of defense related technology should extend well beyond defense application in the way, for example that ARPA continued to support the development of ARPANET even after the establishment of MILNET in 1982 (Chapter 6).

The Clinton administration initially embraced, at least at the rhetorical level, the dual use concept. It implemented a Technology Reinvestment Program (TRP) that had been approved by Congress but not implemented by the Bush administration. The immediate objective of TRP was to advance the entry of new firms into the commercial development of technologies important to the military. Defense procurement reforms would be aimed at modifying military specifications to encourage greater use of products available in commercial markets. It was anticipated that lower costs arising out of economies of scale and other sources of

cost reduction associated with commercial production would reduce acquisition costs.¹¹

A second objective was to enhance the competitive position of U.S. manufacturers in high technology products in international markets (Stokowsky1999)¹². The program, received good marks for being well designed. It initiated a number of projects that were successful in meeting its dual use objectives. A key difference between the TRP and other dual use programs was the emphasis that ARPA placed on the ability of TRP to generate technologies that resulted in commercial products. Other DoD dual use efforts focused primarily on military applications and left subsequent

¹¹ The dual use initiative was proceeding simultaneously with a debate about defense industry diversification policy. Efforts were made by the DoD to encourage defense firms to respond to decline in DoD procurement by diversifying into production for the commercial market—mass transit vehicles in contrast to airframes, for example. The DoD motivation was to preserve the economic viability of enough defense industry firms to assure rivalry among firms in procurement. Some analysts were highly skeptical of the capacity of defense industry firms to successfully pursue diversification. Murray Weidenbaum (1992) argued, for example, that the managerial and technical capacities of most military contractors were best suited to making weapons and that their most appropriate response would be to downsize. Other analysts presented a much more optimistic perspective on defense conversion efforts and have criticized the Pentagon for not pressing conversion efforts more forcefully (Markusen and Yudkin 1992; Gansler 1995).

¹² In the late 1980s and early 1990's both the Bush and Clinton administrations were involved in the development of public institutions to advance commercial technology. Among the more effective were the Advanced Technology Program (ATP) of the National Bureau of standards and Technology and the Cooperative Research and Development Agreement (CRADA) program. These programs involved cooperative agreements and cost sharing between private firms, government laboratories and universities. I have discussed these programs in greater detail in Ruttan (2001: 576-583). For a recent, and very positive evaluation of CRADAs see Adams, Chang and Jensen (2003).

commercial development of the technology largely to the private sector.

In retrospect it is clear that these efforts were badly underfunded and encountered substantial resistance from both the DoD and the large defense contractors.¹³ The 1994 Republican Congress, as part of a general attack on federal technology programs, eliminated the TRP budget as of the end of the 1996 fiscal year (Morrison 1995). Once again efforts to develop a “supply side” or “technology push” approach to strengthening incentives and capacity of firms in the defense industry to advance commercial technology had not met the test of political viability (Higgs 1994; Markusen 1997; Orden 1999; Stokowsky 1999).

¹³ For a retrospective study of experiments by the Air Force to introduce commercial approaches in weapons procurement see Lorell et al. (2000). Lorell and colleagues classified the opportunities for introduction of commercial approaches to procurement of military weapons or components into three categories: (a) pure commercial, (b) commercial but substantially modified for military use; and (c) military unique. The focus of the review was primarily on technologies and practices in (b). Their conclusions were somewhat ambiguous. They found opportunities for substantial cost savings from adoption of commercial parts, technologies, and manufacturing and procurement practices in areas such as digital avionics. At the same time they caution that careful oversight may be required to avoid sacrificing features essential to military performance in exchange for cost savings (Lorell et al 2000: 193-199).

Consolidation

The demise of dual use as a major DoD initiative was confirmed in 1993 when Undersecretary of Defense, William Perry, announced an end to a half century effort by DoD to maintain rivalry among defense contractors by opposing mergers of firms producing comparable products (tanks, aircraft, satellites, submarines and others). The Pentagon change in policy set off a flurry of mergers that reduced the ranks of the largest contractors (those with sales of over \$1.0 billion each) from fifteen in 1993 to four in 1997 (Fig. 8.1).¹⁴ The Pentagon permitted the contractors to write off the merger costs plus a return on investment, on the presumption that the mergers would save the government money in the future (Markusen 2000: 9).

(Insert Fig. 8.1 about here)

At the beginning of the 21st century the United States was still the dominant global producer of a broad range of capital and

¹⁴ “During the 1990s the number of credible aircraft prime integrators for fighters and bombers declined from seven to two. Similarly from 1990 to 1998 the number of U.S. missile manufacturers fell from fourteen to four while space launch vehicle producers declined from six to two. By 2001 only one credible developer of air to air missile producers remained active (Lorell et al 2002: 4). Similar consolidation occurred in Europe (Lorell et al 2002: 6).

skill intensive defense and defense related systems. It still accounted for more than two thirds of defense and defense related R&D spending by the NATO countries and Japan. But the absolute size of defense procurement had declined in real terms to less than half of the 1985 Cold War peak (Flamm 1999: 227). Furthermore the share of output of the United States economy accounted for by the industrial sector had declined to less than 15 percent. Military and defense related procurement had become a smaller share of an economic sector that itself accounted for a smaller share of national economic activity (Ruttan 2002).

An implication that a number of defense intellectuals drew from the structural changes in the defense industrial base and in the structure of the United States economy is that it no longer made sense to think of defense industrial policy in terms of a defense industrial base—a defense industrial base separate from the general industrial base. The policy problem that emerged from this discussion is how the United State should proceed in construction

of a transnational defense industrial base strategy (Markusen 1998; Markusen 2000; Lorell 2002).

In spite of extensive debate about the changing structure of the United States industrial economy and the changing structure of the defense industrial base I have yet to identify a rigorous, comprehensive analysis of the changing structure of the defense industrial base or of the policy implications for defense procurement.

(It is hard to believe that such studies do not exist. Perhaps I have not searched hard enough. For useful perspectives on the changing structure of the defense industry see Flamm (1998, 2000), Markusen (1998) and Lorell (2002).

A FUTURE FOR GENERAL PURPOSE TECHNOLOGY?

It is now time to turn to the third and most difficult question.

Military and defense related R&D and procurement have played an important role in the emergence of most of the general purpose technologies developed in the United States in the 20th century. For

more than a half century the United States has been almost continuously engaged in either hot or cold wars. No matter how unpleasant, the question must be addressed of whether a major war, or threat of a major war, is necessary to induce the United States political and economic institutions to commit the very large resources necessary to generate major new general purpose technologies? In attempting to respond to this question three additional questions must be answered.

Private Sector

The *first* is can the private sector be relied on as a source of major new general purpose technologies? The quick response is that it can not!¹⁵ Each of the general purpose technologies that I have reviewed have required, at least two decades of public support, primarily in the form of military R&D and defense or defense related procurement, to reach the threshold of commercial

¹⁵ In an iconoclastic and widely praised book, *The Economic Laws of Scientific Research*, Terence Keasy (1996) argued that all public sector support for R&D, except possibly military R&D, drives out private sector research—commercially oriented public R&D support substitutes for rather than complements private support for R&D. For a vigorous response see David (1997).

viability. The “animal spirits” that motivate Schumpeterian entrepreneurs have been most vigorous when they sense an opportunity to exploit the technical and economic opportunities opened up by public sector research and technology development.¹⁶

Decision makers in the private sector almost never have access to the patient capital implied by a twenty year, or even a ten year, horizon. This does not mean that the private sector cannot, under the right conditions, be a source of new general purpose technology. Recall that when Mervin Kelly, Director of Research at Bell Laboratories, decided in the mid 1950s that vacuum tubes would become an obstacle to the efficient operation of telephone switchboard he hired William Shockley to explore the potential of solid state physics in communication technology (Chapter 5). The cases reviewed in this book suggest that entrepreneurial firms have often been most successful when they were able to capture the

¹⁶ Referring specifically to the development of the electronic digital computer Kenneth Flamm notes that “the initial demonstration of radically new devices and architectural concepts were pioneered in an environment in which government (typically the military) shared the risks and costs, Development and refinement of the advances largely occurred in a commercial setting, as industry applied these ideas to more business-oriented applications (Flamm 1988: 13)

economic rents generated by complementary public sector investment in research and technology development..

Lewis Branscomb and colleagues at the Harvard Business School note that in the U.S. even the most research intensive firms have almost completely withdrawn from the conduct of basic research and make only limited investment in early stage technology Development.¹⁷ During the first several decades after World War II transient circumstances such as limited international competition or monopoly power reinforced by government regulation, as in the case of Bell Telephone, enabled research intensive firms to take a long term perspective on returns from basic research and early stage technology development. By the early 1990s changes in industrial structure have driven many corporations that had previously been quite research intensive, such as RCA, IBM, Xerox, almost entirely out of basic research

¹⁷ Early stage technology development includes “the technical and business activities that transform a commercially promising invention into a business plan that can attract enough investment to enter a market successfully and through that investment become a successful innovation” (Branscomb and Auerswald 2002: 1) . Branscomb and Auerswald distinguish early stage technology development from incremental or evolutionary technical change in the area of a firm’s core business interests.

and early stage technology development (Branscomb and Auerswald 2002: Auerswald et al. 2003).

Public Sector

A *second* issue is whether adequate public support for commercially oriented R&D might become an important source of new general purpose technologies. I have argued in an earlier book, *Technology Growth and Development* (Ruttan, 2001: 368-422) that molecular biology and biotechnology will represent the source of the most important new general purpose technologies of the early decades of the 21st century.

For more than three decades the molecular genetics and biotechnology research leading to the development of commercial biotechnology products in the pharmaceutical and agricultural industries were funded almost entirely by private foundations, the National Science Foundation, the National Institutes of Health and

the national energy laboratories—largely at government and university laboratories.¹⁸

When the pharmaceutical and agricultural industries decided to enter the field in the early 1980's they found it necessary to make very substantial grants and contracts to university laboratories to obtain a “window” on the advances in the biological sciences and in the techniques of biotechnology that were already underway. Much of the federal funding of biotechnology research was mission oriented—largely directed to solving health problems particularly, after 1970, the “war on cancer.”

I have discussed above the effort of the federal government to develop public-private cooperation with national laboratories (CRADAs) and to provide financial support for public-private cooperation on R&D projects judged to have substantial public goods dimension or long time horizons to commercial viability

¹⁸ In 1938 Max Delbruck at the California Institute of Technology, working with the support of the Rockefeller Foundation, identified DNA as the physical carrier of genetic information. In 1953 James Watson and Francis Crick, working at Cambridge University identified the double helix structure of DNA molecules. In 1973 Stanley Cohen (Stanford) and Herbert Boyer (University of California at San Francisco), supported by NIH grants, demonstrated a method for stably inserting genes from a foreign organism into host genome (Ruttan 2001: 373-374).

such as the Advanced Technology Program (ATP) of the National Bureau of Standards and Technology (NIST). These programs have generated substantial benefits. But they have remained small. And they have had great difficulty maintaining political viability.¹⁹

Public support for significant commercial technology development in the United States has, except in the fields of agriculture and health, had great difficulty in achieving political viability. I find it difficult to anticipate that the private sector can be depended on to become the source of major new general purpose technologies in the foreseeable future

Is War Necessary?

A *third* question that must be answered is whether military and defense related research and technology development can again become a source of major new general purpose technologies. A negative answer to this question is implicit in the discussion of the changing structure of the manufacturing sector of the United

¹⁹ The ATP budget grew from \$67.9 billion in 1993 to \$199.5 million in 1994. Its budget doubled in 1995 and was scheduled to double again in 1996. The growth of the program was curtailed, however, when it came under strong attack after the 1994 mid-term election (Ruttan 2002: 379).

States economy and of the defense industrial base within the manufacturing sector.

Attempts since the end of the Cold War to shift the objectives of defense agencies to enhance their capacity to respond to shorter term tactical missions would seem to reinforce this conclusion.

This trend was induced by an emerging consensus that the threat of system-level war ended with the Cold War and the threat of interstate war among the great powers had virtually disappeared by the end of the twentieth century (Barnett 2004: 59-106). The effect has been to reduce incentives to invest in defense and defense related “big science” and “big technology.”

I remain, however, somewhat skeptical of the apparent consensus that supports these conclusions. A major problem in evaluating technology futures is to know just what is going on right now. It seems quite apparent, for example, that if I had been writing this book in the mid 1970s I would not have noticed, or would have attached little importance, to the commercial potential of research that had been supported by the ARPA Information

Processing Office since the early 1960s. I certainly would not have anticipated the development of the emergence of the INTERNET in the mid-1990s and its dramatic commercial and cultural impacts (Chapter 6).

It would not have been unreasonable in the mid 1980s to anticipate that the massive scientific, technical and financial resources that would be devoted to Strategic Defense Initiative (SDI) , popularly known as Star Wars, could become the source of new general purpose technologies. The purpose of the SDI was to deter an attack on the US. by Soviet ballistic missiles armed with nuclear warheads. Implementation of the system would depend, for example, on advances in sensor, laser, computer and computer software, and guidance and control technologies. It was anticipated that an operational system might become available by 2004. As of yet, however, it is not possible to identify spinoffs that appear to meet the test of commercial general purpose technology

It is quite possible, as in the case of the ARPA information technology program, that two decades is too short a time on which to base and evaluation.²⁰

In spite of these qualifications, however, I find it very doubtful, in the absence of at least a threat of major war, that the United States political system would find it possible to mobilize the very large scientific, technical and fiscal resources that were required to initiate and sustain the development of the military and defense related major general purpose commercial technologies of the second half of the twentieth century.

It was access to large and flexible resources that enabled powerful bureaucratic entrepreneurs such as Leslie Groves and Hyman Rickover (Chapter 3), Joseph Licklider (Chapter 6) and Del Webb (Chapters 3 and 7) to mobilize the very large resources necessary move the general purpose technologies from initial innovation toward military and commercial viability (Doig and

²⁰ For an exceedingly thorough early assessment of the scientific, technical and policy considerations involved in the development and implementation of the SDI see Office of technology Assessment (1985). See also Haley and Merritt (1986), Fought (1987), Molina (1989: 80-89) and Donohue 1994).

Hargrove 1987). They flourished in a political and administrative environment that accommodated their entrepreneurial energies—an environment that no longer exists for military and defense related agencies and firms.

The rationalization of the processes involved in the allocation of resources to research and development in defense and defense related procurement, combined with changes in the structure of defense related industrial base, has placed serious constraints on the ability of military R&D and defense related procurement to continue to play a dynamic role as a source of new general purpose technologies.

When the history of United States technology development in the next half century is eventually written, my guess is that it will focus on incremental rather than on revolutionary changes in both military and commercial technology. It will also be written within the context of slower productivity growth than the relatively high rates that prevailed in the United States during the 1950s and

1960s or during the information technology burble that began in the early 1990s.

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BOX 8.1

MILITARY R&D: THE PRODUCTIVITY PUZZLE²¹

Is publicly funded military R&D a source of technology development and productivity growth? In earlier chapters I have presented historical case studies of the role of military procurement in technology development for six general purpose technologies. The results seem to be in direct contradiction to a number of very careful econometric studies that show that measured private and social rates of return to military R&D have been very low and have had no discernible effect on industrial productivity growth in the United States (Lichtenberg 1989: 275; Lichtenberg 1994).

There is a long history of studies of private and social rates of return to R&D. These studies trace back to the now classic studies of rates of return to agricultural research by Griliches (1858) and to industrial research by Mansfield and Beardsley (1977). The results

²¹ I am indebted to Paul A. David and Frank R. Lichtenberg for comments on an earlier draft of this box.

of the wide body of firm level, sector level and economy wide level studies, combined with studies of the sources of productivity growth, have supported a view that the social rates of return to R&D have generally exceeded the rates of return on almost any other form of investment available to the United States economy. These high social rates of return contributed to a consensus that the United States was substantially under investing in R&D—and that this under investment was a substantial constraint on economic growth. Because of the spillover of R&D benefits in the form of consumers and producers surplus even privately funded R&D shared the characteristics of public goods--the economic unit that generates the new technology can capture only a portion of the social benefits deriving from the research. The policy implication that has generally been drawn is that the United States should expand public sector support for R&D to correct private sector underinvestment.

The generality of the above conclusion has been challenged, however, by studies by Lichtenberg (1984; 1989) and others that

have attempted to measure the private rates of return to firms that conduct publicly funded research and technology development and of the firm and economy wide spillover effects of such R&D. A large number of studies have failed to find significant private or social rates of return from publicly funded research conducted by private firms. However, “privately funded R&D in manufacturing industries is found to yield a substantial premium over the rate of return from ‘own productivity improvements’ derived from R&D performed with government funding” (David, Hall and Toole 2000: 498).

It has been suggested that one explanation for these results may be that a high percentage of firm level federally funded industrial research has been conducted by defense or defense related firms. Neither the R&D nor the products resulting from such R&D are subject to a market test it. The design of technology, firm level costs, and returns are heavily influenced by bilateral bargaining. Research results and technology development information is usually classified. A substantial share of the

products derived from the federally funded R&D are often sold back to the government. Under these institutional arrangements conventional measures of profitability and productivity may not be appropriate (Griliches 1995: 82).

Tests conducted against the impact of federal funding on firm level R&D or profitability do not, however, represent an adequate test of the effects of public sector, and particularly of defense sector, R&D on economic performance. Public funding is often a complement (rather than a substitute) to private R&D and thus may enhance sector level profitability and productivity. In addition defense or defense related procurement of services and products resulting from R&D may represent a substantial stimulus to firm level research and technology development (Lichtenberg 1994).

A number of early studies contributed to a presumption that much of the R&D conducted or funded by the public sector simply substituted for private sector R&D—that it crowded out private sector R&D. In an attempt to test the substitution hypothesis David, Hall and Toole (2000) conducted a critical review of the

large body of econometric research studies that attempted to shed some light on the issue of whether public sector R&D has been a substitute for, or a complement to, private sector R&D. After sorting out the subset of studies that were adequately designed to test the substitution hypothesis they found that the result from about one-third were consistent with the substitution hypothesis while two-thirds were consistent with the complementarily hypothesis. I find it particularly significant that almost all of the higher level aggregate studies were consistent with the complementarily hypothesis. The implication is that the more aggregate studies were able to capture elements of complementarily not detected at the individual firm level.

My own view is that we do not yet have, and perhaps cannot have, a body of rigorous econometric evidence against which to evaluate the economic impact of defense and defense related R&D and procurement. David, Hall and Toole explicitly eschewed any effort to assess the magnitude of the economic effect of complementary. What are the implications for the attempt that I

have made in this book to assess the significance of military procurement on the development of commercial technology? My answer is that careful narrative analysis of individual cases is at present, a more effective method of capturing the effects of complimentary than econometric analysis. Paul A. David has also pointed out to me that narrative analysis may be more able to capture the long term or lagged effects of public R&D investments (David, Letter , April 11, 2004).

It is particularly important to assess the extent to which military procurement has induced both demand and supply side forces that have shortened the process of transition from initial concept to commercialization of new general purpose technologies. The Semi-Automatic Ground Environment (SAGE) program (Chapter 5) and the Apollo space mission (Chapter 7) drove computer and microprocessor technology rapidly down their learning curves and advanced the development of commercial computer technology by at least a decade. Similar examples have been presented in Chapters 2-7 of this book.

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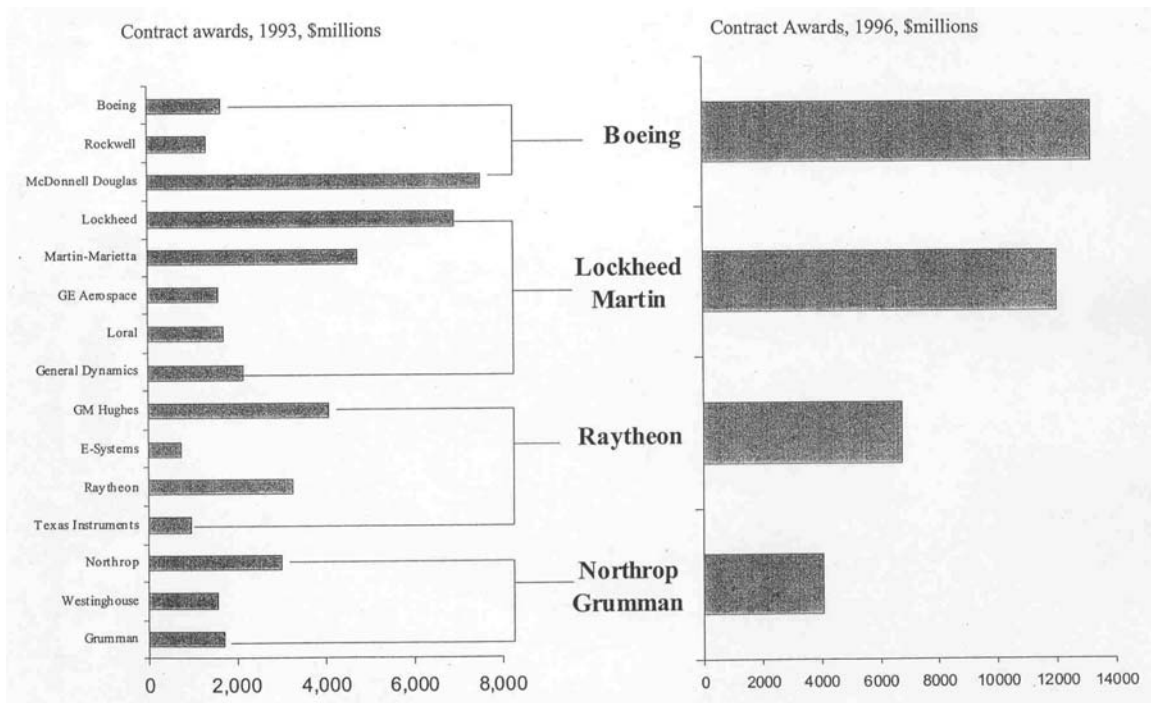
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Figure 8.1. U.S. Defense Merger in the 1990s



Source: Ann Markusen, 1998. "The Post-Cold War Persistence of Defense Specialized Firms." In *The Defense Industry In the Post-Cold War Era: Corporate Strategies and Public Policy Perspectives*, eds. G. I. Sussman and S. O'Keefe, p. 123. Amsterdam, Netherlands: Elsevier Science.