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IS WAR NECESSARY FOR ECONOMIC GROWTH?

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PREFACE

In a book published in 2001, *Technology, Growth and Development: An Induced Innovation Perspective*, I discussed several examples but did not give particular attention to the role of military and defense related research, development and procurement as a source of commercial technology development. A major generalization from that work was that government had played an important role in the development of almost every general purpose technology in which the United States was internationally competitive.

Preparation for several speaking engagements following the publication of the book led to a reexamination of what I had written. It became clear to me that defense and defense related institutions had played a predominant role in the development of many of the general purpose technologies that I had discussed. The role of military and defense related research, development and procurement was sitting there in plain sight. But I was unable or unwilling to recognize it!

It was with considerable reluctance that I decided to undertake the preparation of the book I discuss in this paper, *Is War Necessary for Economic Growth? Military Procurement and Technology Development*. In this paper I also draw on material from my earlier book, *Technology Growth and Development: An Induced Innovation Perspective.*

IS WAR NECESSARY FOR ECONOMIC GROWTH?

INTRODUCTION

A major objective in this paper is to demonstrate that military and defense related research, development and procurement have been major sources of technology development across a broad spectrum of industries that account for an important share of United States industrial production.

I argue that the United States and the global technological landscape would be vastly different in the absence of the contribution of military and defense related research, development and procurement. I also argue that as we look to the future the contribution of defense and defense related technology research, development and procurement to United States industrial production will be smaller than in the last half century.

An implication is that in the future the rate of productivity and income growth in the United States economy will be slower than during the first two post-World War I decades or than during the information technology bubble that began in the early 1990s.

In the first section of this paper I first review the role of military and defense related research, development and procurement as sources of commercial technology development in a series of general purpose technologies. In later sections of the paper I turn to the industrial policy implications of my review of the several general purpose technologies.

It is worth recalling, before turning to more recent history, that knowledge acquired in making weapons played an important role in the industrial revolution. James Watt turned to John Wilkinson, a canon-borer who had invented the only machine in all of England that could drill through a block of cast iron with accuracy, to bore the condensers for his steam engines. In the United States, what came to be termed *the American system of manufacturing* emerged from the New England armory system of gun manufacture. In 1794 President George Washington, disturbed by the inadequate performance and corruption of the contract system of gun procurement, proposed a bill which the Congress passed to set up four public armories to manufacture and supply arms to the U.S. Army. The Springfield Armory became an important source of wood and metal working machines. Guns with interchangeable parts were first developed at the Harpers Ferry Armory.

SIX GENERAL PURPOSE TECHNOLOGIES

The general purpose technologies discussed in this section—in the aircraft, nuclear power, computer, semiconductor, the internet, and the space communication and earth observing industries have exerted a pervasive impact on product development and productivity growth across a broad spectrum of United States industries. Defense and defense related research, development and procurement have played an important role in advancing the technology in these several industries. They have each involved radical or revolutionary rather than incremental changes in technology. I do not, in my book or in this paper, discuss the large number of secondary spin-offs from military or defense related research, development and procurement. A classic example is the microwave oven, a spin-off from the research and development involved in the invention of radar.

The Aircraft Industry

The U.S. military has been intimately involved in aircraft development since the Army Signal Corps purchased its first plane from the Wright Brothers in 1907. Procurement of military aircraft and support for aeronautics research and development have been the two principle instruments used to support the development of the aircraft industry.

The aircraft industry is unique among manufacturing industries in that a government research organization was established to support research on technology development for the industry. By the mid-1920s research conducted or supported by the National Committee on Aeronautics (NACA) was beginning to have a major impact on aircraft design and performance. Most of the early advances that resulted from NACA research and development were "dual use" – applicable to both military and commercial aircraft. Every American airplane and every aircraft engine that was deployed in World War II had been tested and improved by NACA engineers. These advances had been achieved at remarkably low cost. When the Soviet Union launched Sputnik in 1957 it set in motion a series of events that led to NACA being absorbed into a new agency, the National Aeronautics and Space Administration (NASA).

The relationship between military procurement and commercial technology development is illustrated with particular force in the development of the Boeing 707 and 747. Boeing engineers began to consider the possibility of developing a commercial jet airliner in the late 1940s. It was considered doubtful that initial sales could justify development costs. The problem of financing development costs for what became the Boeing 707 was resolved when Boeing won an Air Force contract to build a military jet tanker designed for in-flight refueling of the B-52 bomber.

Development of the Boeing 747 followed a somewhat different pattern. In 1965 Boeing lost an Air Force competition to design a large military transport to Lockheed. Starting with the design they had developed for the military transport Boeing went on to design what became the Boeing 747 wide bodied commercial jet. By the early 1970s the Boeing 747 was recognized as having set the standard that defined technological maturity in the modern commercial jet air transport industry.

Nuclear Power

The initial development of electric power took place entirely within the private sector. A primary focus of the research team that Thomas Edison established at Menlo Park in 1876 was the development of a system for the generation and distribution of electric power. Over the next half century the electric power industry became a primary source of economic growth in the United States economy. It made possible the electrification of homes, factories and farms.

Atoms for War. Demonstration of the feasibility of controlled nuclear fission by a team directed by the young Italian physicist, Enrico Fermi, at the University of Chicago Stagg Field laboratories in October 1942, set the stage for an active role of the United States military and defense related institutions in technology development for the power industry. From its beginning it has not been possible to understand the development of the nuclear power industry apart from the military application of nuclear energy.

The steps that led to Fermi's demonstration of the possibility of controlled nuclear fission were set in motion in 1938 when two German chemists, Otto Han and Fritz Strassman, of the Kaiser Wilhelm Institute in

Berlin, found they could split atoms by bombarding their nuclei and with neutrons. It was immediately recognized in the physics community in both Europe and the United states that if the energy liberated by splitting the uranium atom could be controlled and directed it might be possible to construct a nuclear weapon more powerful than anything currently available.

Steps were taken to bring the implications of the Han-Strassman discovery to the attention of President Roosevelt. After considerable delay responsibility for the production of an atomic bomb was assigned to the Army which in turn reassigned it to the Army Corps of Engineers. In June 1942 the Corps formed the Manhattan District, under the direction of Colonel Leslie Groves, to oversee and construct an atomic bomb. The design and production of the bomb involve the establishment of a system of laboratories and the construction of three entirely new cities at Oak Ridge, Tennessee, Hanford, Washington and Los Alamos, New Mexico.

Atoms for Peace. In 1946 authority to develop, promote, and regulate nuclear technology for both military and civilian purposes was transferred to a newly established Atomic energy commission. President Eisenhower's "Atoms for Peace" speech before the United Nations in December 1953, committed the United States to a much more active role in commercial nuclear power development.

In December 1954 the Atomic Energy Commission, under considerable pressure from Congress and the power industry, announced a Power Demonstration Reactor Program. At the time the Power Demonstration Project was announced the Atomic Energy Commission had already made a decision to cooperate with the Duquesne Power and Light to build a pressurized water reactor at Shippingport, Pennsylvania. That decision was a direct consequence of a 1950 decision by the Navy to develop a light water nuclear reactor to propel its first nuclear powered submarine.

In 1962 there were seven prototype commercial nuclear power plants using different cooling and moderator technologies in operation. By the mid-1960s however, nuclear power reactor experimentation was over. The Westinghouse pressurized water reactor and the General Electric boiling water reactor became the industry standards. Nowhere were electrical utility firms heavily involved in nuclear research. They assumed that a nuclear reactor was just another way to boil water!

By the mid-1970s the United Nuclear power industry seemed poised for rapid expansion. A petroleum supply crisis that began in the early 1970s was expected to increase demand for nuclear power. It was completely unexpected that a combination of safety, health and environmental concerns would bring the expansion of nuclear power capacity to a halt by the end of the decade. The light water reactors of the 1960s were largely due to engineering and cost considerations no longer commercially viable in the United States.

The Computer Industry

The first all-purpose electronic digital computer was constructed by John W. Machly and J. Prosper Eckert at the University of Pennsylvania's Moore School of Electrical Engineering in 1946. Development of the machine, the Electric Numerical Integrator and Calculator (ENIAC) was funded by the Army's Aberdeen Ballistics Missile Laboratory. The first program run on the ENIAC was a simulation of the hydrogen bomb ignition. A second computer developed by the Moore School group, the Electronic Discreet

Variable Computer (EDVAC), incorporated a stored program and sequential processing. In what came to be referred to as the von Neuman architecture the processing unit of the computer fetches instructions from a central memory that stores both data and programs, operates on the data, and returns the results to the central memory.

Eckert and Mauchly formed the Electronic Control Company in June 1946. A second pioneering company, Engineering Research Associates (ERA) was also founded in 1946 by staff members of the Naval Communications Supplemental Activity located in St. Paul who had been involved in the development of computers in support of the Navy's work in cryptography. Both firms were acquired by Remington Rand. Both were disappointed by the lack of enthusiasm by Remington for commercial computer development.

It was the Korean War that led to a decision by IBM to enter the market for commercial computers. The IBM Defense Calculator, renamed the 701, was formally dedicated in April 1953. Intensification of the Cold War in the early 1950s played a critical role in the decision of IBM to manufacture a fully transistorized commercial computer. The impetus came from a decision by IBM to cooperate with the MIT Lincoln Laboratory in the development of the Semi-Automatic Ground Environment funded by the U.S. Air Force. The objective of the SAGE project was to detect alien aircraft, select appropriate interceptor aircraft, and determine anti-aircraft trajectories.

As the SAGE project was being completed IBM was producing six different computer lines, each of which had incompatible operating systems. In 1965 IBM introduced the first of the 360 family of computers designed for both military and commercial application. The 360 family of computers used integrated circuits rather than transistors. No matter what size all contained the same solid state circuits and would respond to the same set of instructions. The 360 platform became the industry standard for the rest of the 1960s and 1970s.

The alternative to the path followed by IBM was to design computers specifically for defense and defense-related applications that would be faster than any IBM machine at floating point arithmetic. The 1964 Control Data 6000 designed by Seymore Cray was the first machine that could properly be termed a supercomputer. In 1972 Cray and several colleagues left Control Data to form a new company, Cray Research, which produced the world's fastest computers. Computers designed by Cray dominated the market for the high-end computing used by the military and defense related agencies and industries until after the end of the Cold War when Cray failed to find a market for his newest computer.

The Semiconductor Industry

The invention of the transistor and the microprocessor were the two major inventions facilitating the emergence of the computer as a general purpose technology. It was understood even in the 1940s that the speed, reliability, physical size and heat generating properties of the vacuum tubes used in telephone-switching devices would become a major technical constraint on electric switching. These same limitations were also recognized as major constraints on the development of faster and smaller computers.

After World War II Bell Laboratories formed a solid state research program, directed by William Shockley, to advance knowledge that might be used in the development of completely new and improved components and apparatuses for communication systems. In attempting to understand why a prototype semiconductor amplifier developed by Shockley had failed, two colleagues, John Bardeen and Walter Brattain, produced the first working transistor (the point-contact design) on December 15, 1947. Their work led to an effort by Shockley to develop the bipolar junction transistor. Advances in engineering, particularly the development of techniques for producing germanium and silicon crystals, were required before production of the junction transistor became feasible.

Until the late 1950s transistors were discreet devices—each transistor had to be connected to other transistors on a circuit board by hand. In the mid-1950s Texas Instruments, then the leader in silicon transistor production, initiated a research program under the direction of Jack Kilby, to repackage semiconductor components to reduce circuit interconnections. In 1958 these efforts resulted in a crude integrated circuit. However, the cost of assembling the separate components of Kilby's device by hand were too expensive for commercial application. At about the same time Robert Noyce and Gordon Moore of Fairchild Semiconductor independently invented the *planar process* which involved incorporating very small transistor and capacitors on a small sliver of silicon and adding microscopic wires to interconnect adjacent components.

Two types of integrated circuits were critical to advancing computer technology. One is a memory chip that allows the computer to temporarily remember programs and other information. The other is the microprocessor which processes the information. The first microprocessor was developed at Intel in the late 1960s. Technical progress in the integrated circuit era has moved along a trajectory toward increasing density of circuit elements per chip. In 1965 Gordon Moore, the co-founder of Intel, predicted that the number of transistors per integrated circuit would double every 18 months. This has come to be referred to as Moore's Law.

The potential military applications of transistors and semiconductors were immediately apparent. The transition between the initial invention of the transistor and the development of military and commercial applications of semiconductors and integrated circuits was substantially funded by the Army Signal Corps. By 1953 the Army Signal Corps was funding approximately 50 percent of transistor development at Bell Laboratories. The Signal Corps' own engineering laboratory developed the technology to replace hand soldering of components. In 1953 the Signal Corps underwrote the construction of a large Western Electric transistor plant in Lauderdale, Pennsylvania. By the mid-1950s it was also subsidizing facility construction by General Electric, Ratheon, RCA and Sylvania.

As late as 1960 defense and defense related procurement accounted for almost 80 percent of semiconductor sales. Military and defense related demand pushed semiconductor technology rapidly down the design and production learning curve. The diffusion of knowledge and the entry of new firms was encouraged not only by direct subsidies but by the military procurement policy of "second sourcing." Demand for semiconductors continued to be dominated by military and defense related applications as the need for increasingly powerful computers continued to grow well into the 1970s.

The Internet

The development of the Internet involved the transformation of a computer network initially established in the late 1960s by the Defense Department Advanced Research Projects Agency (ARPA). Joseph Lickleider, Director of the ARPA Information Processing Techniques Office (IPO), initially visualized a system of “time sharing” in which a single centrally located computer would be accessed by a number of users with individual terminals connected to the central computer by long distance telephone lines. Messages would be broken into small “packets” and routed over the distributed system automatically rather than manually.

In early 1971 ARPA awarded a contract to Bolt, Bernek and Newman, a small high technology firm located in the Cambridge, Massachusetts area, for the development of a computer-interface message processor (IPM) that would be able to route packets along alternative routes. In a remarkably short time, only nine months after the contract was awarded, the system design was in place. In order to galvanize the several university and defense system contractors to complete the effort to get the system on line, ARPA project Director Lawrence Roberts made a commitment to demonstrate the system, then termed the ARPANET, at the First International Conference on Computer Communication to be held in October 1972 in Washington, D.C. The spectacularly successful demonstration convinced skeptics in the computer and telephone industries that packet switching could become a viable commercial technology.

Although the potential capacity of the ARPANET as a communication tool was apparent, at least to those who participated in its development, neither the Defense Department sponsors of the research or the members of the design team anticipated that it would take a quarter of a century to resolve the technical and institutional problems necessary to release the potential of the ARPANET, or that its primary use would be for personal and commercial e-mail rather than for transmitting data and for research collaboration.

A major institutional issue included how to separate defense related and commercial applications. In 1982 a decision was made to split ARPANET into a research oriented network, still to be called ARPANET, and an operational military network to be called MILNET that would be equipped with encrypton. A second ideologically loaded institutional issue was how to transfer what became the INTERNET from public to private operation. The process of privatization was largely completed by the mid-1990s, thus opening the way for completion of global "network of networks"—the World Wide Web.

Since it was transferred to civilian control, users have generally lost sight of the contribution of military procurement to the development of the INTERNET. From the perspective of the individual or commercial user is the critical date that marked the explosion of the INTERNET into the business and cultural scene is 1994, the year an easy-to-use INTERNET browser with secured transaction called Netscape, based on research conducted at the University of Illinois, was launched. It is clear in retrospect, however, that no other public or private organization than ARPA was prepared to provide the scientific, technical and financial resources to support what became the INTERNET.

The Space Industries

The launching of Sputnik, the first earth observing satellite on October 4, 1957 and a second satellite in May, 1968 by the Soviet Union challenged the assumption of United States scientific and technological leadership. President Eisenhower and his immediate military and science advisors did not, however, appear to be greatly alarmed by the apparent Soviet leadership. The United States had been flying spy planes (the U-2) over the

USSR for more than a year and had previously initiated a program to develop satellite communication and observation capacity. Eisenhower saw Sputnik as a useful precedent for “an international freedom of space” policy.

United States’ capacity in missiles and satellite science and technology in the early post-World War II period was based almost entirely on the acquisition of the scientific and technological resources of the German rocket team led by Werner Von Braun. The United States Army was able to acquire most of the important German technical personnel and documents and almost all of the remaining V-2 rockets. After a brief debriefing at Wright Field the team was transferred to Fort Bliss (Texas) and then in 1940 to the Redstone Arsenal in Huntsville, Alabama.

In April, 1958 President Eisenhower approved plans to launch a satellite as part of the United States’ contribution of the scientific activities of the International Geophysical Year (IGY). The IGY satellite program, Project Vanguard, was assigned to the Naval Research Laboratory. Under pressure from the White House, a decision was made to commit the new and untested Vanguard rocket (Test Vehicle 3) into putting a satellite in orbit at Cape Canaveral in early December. “Finally,” writes Paul Dickson, “at precisely 11:14:55 on Friday, December 6, 1957, with the whole world watching, the slender vehicle rose a few feet off the launch platform, shuddered slightly, buckled under its own weight, burst into flames and collapsed. Its tiny 3.2 pound payload, thrown free of the fire, rolled into the scrub brush, and started beeping.” After the Vanguard failure the Army Ballistics Missile Agency was permitted to employ its Jupiter 3 ICBM to launch the Explorer 1, the first successful United States satellite, on January 31, 1958. After a series of failures the Vanguard I satellite was successfully launched on February 17, 1959.

At the time of the Sputnik crisis the General Intelligence Agency, the Air Force and several defense contractors were already working on a surveillance satellite program termed Corona. Corona was so secret that for several months after its initiation, CIA Chief Allen Dulles ordered that all details were to be transmitted verbally. The first fully successful CORONA satellite, launched on August 18, 1960, yielded photo coverage of a greater area than the total produced by all the U-2 missions over the Soviet Union. As late as 1999 Cloud and Clarke insisted that the impact of the CORONA program was so pervasive that it has been difficult to identify any significant Geographic Information System technologies, applications, or data sets that did not have a primary or secondary origin in collaboration with the secret assets of the military and intelligence institutions.

By the early 1960s the potential strategic and economic contributions of the several space programs were beginning to become apparent. The program of the Army Ballistic Missile Agency, motivated by the energetic bureaucratic entrepreneurship of Von Braun, had set in motion the technology that led to the NASA manned space flight program, Project Vangaard, has laid the groundwork for NASA initiatives in space science and space communications technology. The Air Force surveillance projects had led to advances in weather forecasting and earth observing systems. I discuss the history of these developments, including the role of the military and defense related institutions and the troubled history of privatization efforts, in greater detail in *Is War Necessary for Economic Growth.*

TECHNOLOGICAL MATURITY

After initially experiencing rapid or even explosive development, general purpose technologies often experience a period of maturity or stagnation.

One indicator of technological maturity has been a rise in the scientific and technical effort required to achieve incremental gains in a performance indicator. In some cases renewed development has occurred along a new technological trajectory.

Measurable impact of a new general purpose technology on industry or sector level productivity often does not occur until a technology is approaching maturity. Robert Solow famously commented only a decade ago that he saw computers everywhere except in the productivity statistics.

The electric utility industry represents a classic example. Although the first commercially successful system for the generation and distribution of electricity was introduced by Thomas A. Edison in 1878, it was not until well into the 20th century that electrification of factory motive power began to have a measurable impact on productivity growth. Between the early 1920s and the late 1950s the electric utility industry was the source of close to half of U.S productivity growth.

Electric power generation from coal fired plants reached technological maturity between the late 1950s and early 1960 with boiler-turbine units in the 1,000 megawatt (MW) range. The technical design frontier was limited by the ability of boilers to withstand high temperature and pressure. It is possible that the exploitation of renewable energy resources or development of other alternative energy technologies (possibly hydrogen) could, over the next several decades, emerge as a possible new general purpose technology. However, none of the alternative technologies, including nuclear power, appear at present to promise sufficient cost reduction to enable the electric power industry to again become a leading rather than a sustaining source of economic growth in the U.S. economy.

Aircraft is an example of an industry in which a mature technological trajectory was followed rapidly by transition to a new technological trajectory. Piston propeller aircraft propulsion reached technological maturity in the late 1930s. The scientific and technical foundations for a transition to a jet propulsion trajectory were well underway by the late 1930s. In the absence of military support for R&D during World War II and military procurement during the Korean War the transition to commercial jet aircraft would have occurred much more slowly. The Boeing 747, introduced in1969, epitomized the mature commercial jet transport.

By the late 1960s there were indications that mainframe computer development was approaching technological maturity. However, 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. Support by defense and space agencies contributed to the advances in supercomputer speed and power into the early 1990s. By the late 1990s substantial concern was being expressed about the sources of future advances in computer performance.

A continuing concern in the field of computer, and information technology more generally, is how long Moore's law, which has been interpreted to predict that the number of components per silicon chip in a microprocessor could be expected to double every eighteen months. It may be premature to characterize the computer and information technology industries as approaching maturity. But the collapse of the communication industry bubble beginning in the late 1990s and continuing consolidation of the industry suggests some caution about the more extravagant expectations of containing logistical growth.

In concluding this section let me again indicate why I have given so much attention to the issue of technological maturity. Historically, new general purpose technologies have been the drivers of productivity growth across broad sectors of the U.S. economy. It cannot be emphasized too strongly that if either scientific and technical constraints or cultural and institutional constraints should delay the emergence of new general purpose technologies over the next several decades it would surely result in a slowing of productivity growth in the U.S. economy. Endless novelty in the technical elaboration of existing general purpose technologies can hardly be sufficient to sustain a high rate of economic growth! In the case of the general purpose technologies that emerged as important sources of growth in the U.S. during the last half of the twentieth century it was primarily military and defense-related demand that initially drove these emerging technologies rapidly down their learning curves.

IS WAR NECESSARY?

As the general purpose technologies that were induced by military and defense related R&D and procurement during the last half century have matured it is necessary to ask if military and defense related R&D and procurement will continue to be an important source of commercial technology development.

Changes in Military Doctrine

During the first two post-World War II decades it was generally taken as self evident that substantial spin-off of commercial technology could be expected from military procurement and defense related R&D. The spin-off paradigm had emerged in an era when the United States dominated world technology and national defense dominated United States technology development. The slowing of economic growth in the U.S. economy that began in the early 1970s led to a questioning of the continued relevance of the spin-off paradigm.

Beginning in the mid-1980s and into the mid 1990s "dual use" military-commercial technology, became the conventional wisdom on how to resolve the problem of rising cost and declining quality in post-Cold War military procurement. The Clinton administration initially embraced, at least at the rhetorical level, the dual-use concept.

In retrospect it seems clear that the dual use and related efforts were badly under funded. They encountered substantial resistance from both the Department of Defense and the large defense contractors. The 1994 Republican Congress, as part of a general attack on federal technology development programs, sharply reduced the budget of the National Bureau of Standards and Technology's Advanced Technology Program and eliminated the budget for the Technology Reinvestment Program.

The demise of dual use as a major DOD initiative was confirmed in 1993 when the Deputy Secretary of Defense announced an end to a half century effort by DOD to maintain rivalry among defense contractors producing comparable products (tanks, aircraft, submarines and others). The Pentagon change in policy set off a flurry of mergers and acquisitions that reduced the ranks of the largest contractors, those with sales of over $1.0 billion, from fifteen in 1993 to four in 1996 (Figure 1).

By the early 1990s it was becoming clear that changes in the structure of the U.S. economy, of the defense industries, and of the defense industrial base had induced substantial skepticism that the military and defense related R&D and procurement could continue to play an important role in the generation of new general purpose commercial technologies. By the turn of the century the share of output in the U.S. economy accounted for by the industrial sector had declined to 1ess 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. The absolute size of defense procurement had declined to less than half of the 1985 Cold War peak.

Since the end of the Cold War the objectives of the defense agencies have shifted toward enhancing their capacity to respond to shorter term tactical missions. This trend was reinforced by an emerging consensus that the threat of system-level war ended with the Cold War. Many defense intellectuals had come to believe that major interstate wars among the great powers had virtually disappeared. The effect has been to reduce incentives to make long term investments in defense and defense related “big science” and “big technology”.

Would it take a major war, or threat of war to induce the U.S. government to mobilize the necessary scientific, technical and financial resources to develop new general purpose technologies? If the United States were to attempt to mobilize the necessary resources would the defense industries and the broader defense industrial base be capable of responding? It was access to large and flexible resources that enabled powerful bureaucratic entrepreneurs such as Leslie Groves, Hyman Rickover, Joseph Lickleider and Del Webb to mobilize the scientific and technical resources necessary to move new general purpose technologies from initial innovation toward military and commercial viability. They flourished in a more open political and administrative environment that no longer exists for military and defense related agencies and firms.

Private Sector Entrepreneurship

Can private sector entrepreneurship be relied on as a source of major new general purpose technologies? The quick response is that it cannot! When new technologies are radically different from existing technologies and the gains from advances in technology are so diffuse that that they are difficult to capture by the firm conducting the research and early stage technology development private firms have only weak incentives to invest in scientific research or technology development. Most major general purpose technologies have required several decades of public or private support to reach the threshold of commercial viability.

Decision makers in the private sector rarely have access to the patient capital implied by a twenty year or even a ten year time horizon. Lewis Branscomb and colleagues at the Harvard John F. Kennedy School of Public Affairs note that many of the older research-intensive firms have almost completely withdrawn from the conduct of basic research and are making only limited investments in early stage technology development (Branscomb and Auerswald 2002).

Entrepreneurial firms have often been most innovative when they have had an opportunity to capture the economic rents opened up by complementary public investment in research and technology development. Even the most innovative firms often have great difficulty pursuing more than a small share of the technical opportunities opened up by their own research. It is difficult to anticipate that the private sector will, without substantial public support for R&D, become an important source of new general purpose technologies over the next several decades.

Public Commercial Technology Development

The conclusions of the last two sections—that neither defense and defense related R&D and procurement or private sector entrepreneurship can be relied on as an important source of new general purpose technologies forces a third question onto the agenda. Could a more aggressive policy of public support for R&D directed to commercial technology development become an important source of new general purpose technologies?

Since the mid-1960s the federal government has made a series of efforts to initiate new programs in support of the development and diffusion of commercial technology. Except in the fields of agriculture and health these efforts have had great difficulty achieving economic and political viability. Funding of the programs authorized by the 1965 State Technical Services Act, which provided support for universities to provide technical assistance to small and medium-size businesses, was a casualty of the Vietnam War. The very successful federal-private cooperative Advanced Technology Program of the National Bureau of Standards and Technology barely survived the Congressional attacks on federal technology programs following the 1994 mid-term elections. The SEMATECH semiconductor equipment consortium represents another model for successful public-private cooperation in technology development. But it has not been replicated in other industries. The U.S. has not yet designed a coherent set of institutional arrangements for public support of commercial technology development. Furthermore, even the successful programs referred to here have been designed to achieve short-term incremental gains rather than the development of new general purpose technologies.

R&D in molecular genetics and biotechnology represents a major exception. I argued in *Technology Growth and Development* that molecular biology and biotechnology will represent the source of the most important new general purpose technologies of the early decades of the twenty-first century. For more than three decades, beginning in the late 1930s, the molecular genetics and biotechnology research leading to the development of commercial biotechnology products in the pharmaceutical and agricultural industries was 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.

When firms in the pharmaceutical and agricultural industries decided to enter the field in the 1970s they found it necessary to make very substantial grants to and contracts with university laboratories to obtain a "window" on the advances in the biological sciences and in the techniques of biotechnology that were already underway in university laboratories. When defense agencies in the United States and the USSR began to explore the development of bio-weapons and their antidotes they also found it necessary to access capacities in molecular biology that were available only in university and health agency laboratories.

ANTICIPATING TECHNOLOGICAL FUTURES

A major problem in assessing technology futures is to be able to know and anticipate the implications of what is going on right now. It seems quite apparent, for example, that if I had been writing this paper (or my recent book) in the mid-1970s I would not have noticed, or would have attached little importance, to the commercial potential of research on artificial intelligence that had been supported by the DARPA Information Processing Office since the early 1960s. I certainly would not have anticipated the development or emergence of the Internet and its dramatic commercial and cultural impacts. Today I find it equally difficult to separate solid scientific and technical assessment from the hype about the promise of the nanotechnologies.

It is possible, however, to identify two scientific and technical challenges that can be expected to induce very substantial demands for public and private sector investment to advance scientific knowledge and technology development during the next half century.

Pests, pathogens and disease. One is the demand to develop the knowledge and technology to confront the co-evolution of pests, pathogens and disease with control agents. We have been increasingly sensitized to the effects of this co-evolution by the resurgence of tuberculosis and malaria, the emergence of new diseases such as Ebola and AIDS, and the threat of a new global influenza epidemic. The co-evolution of human, nonhuman animal and crop plant pests, pathogens, and diseases with control technologies means that chemical and biological control technologies often become ineffective within a few years or decades. This means, in turn, that maintenance research - the research necessary to sustain present levels of health or protection - must rise continuously as a share of a constant research budget.

At present, research and development in the field of health tends to be highly pest and pathogen specific. It is not apparent that research is currently underway that will generate broad general purpose radical medical and health related technologies capable of addressing the demand for long-term sustainable protection against the co-evolution of pests, pathogens and disease with control technologies.

Climate change. Measurements taken in the late 1950s indicated that carbon dioxide (CO2) was increasing in the atmosphere. Beginning in the late 1960s, computer model simulations indicated possible changes in temperature and precipitation that could occur due to human-induced emission of CO2, nitrous oxides (N20) and other greenhouse gases into the atmosphere.

By the early 1980s, a fairly broad consensus had emerged in the climate change research community that greenhouse gas emissions could, by 2050, result in a rise in global average temperature by 1.5 to 4.5C (about 2.7 to 8.0F), and a complex pattern of worldwide climate changes. By the early 2000s it was clear, from increasingly sophisticated climate modeling exercises and careful scientific monitoring of earth surfaces change, such as the summer melting of the north polar ice cap, that what Roger Ravelle had characterized as a "vast global experiment" was well underway. It was also apparent that an alternative to the use of carbon based fossil fuels would have to be found.

Modest efforts have been made since the mid-1970s to explore renewable energy technologies. Considerable progress has been made in moving down the learning curves for photovoltaics and wind turbines. The Bush administration has placed major emphasis on the potential of hydrogen technology to provide a pollution free substitute for carbon-based fuels by the second half of the century. The environmental threats and economic costs of continued reliance on fossil fuel technologies are sufficiently urgent to warrant very substantially larger public support in the form of both private sector R&D incentives and a refocusing of effort by the national energy laboratories on the development and diffusion of alternative energy technologies.

I would like to reemphasize two points. The first is that, while immensely important, successful pursuit of the health and energy technologies discussed above will not resolve the problem of achieving rapid economic growth in the U.S. economy. Both are maintenance technologies. They are necessary to prevent the deterioration of health and environment.

The second is that preeminence in scientific research is only loosely linked to preeminence in technology development. In a number of U.S. high technology industries it has been military procurement that enabled firms to move rapidly down their technology learning curves. The development of new general purpose technologies will require much more aggressive public support of commercial technology development as it becomes less possible to rely on defense and defense related procurement.

PERSPECTIVES

In this paper, and in my book, I have reviewed the role that military research and development and procurement have played in the commercial development of the aircraft, nuclear power, computer, semiconductor, the Internet and the space communication and earth observing industries. In *Is War Necessary for Economic Growth?*, in each case commercial technology development would have been substantially delayed in the absence of military and defense related research, development and procurement. I give particular attention to procurement since it was procurement that drove new technologies rapidly down their learning curves during the early stages of development.

I have not argued that these defense and defense related technologies can be adequately evaluated primarily in terms of their impact on commercial technology development. They must be evaluated primarily in terms of their cost effectiveness in meeting military mission objectives. They have been inordinately expensive. And in most cases the cost-effectiveness calculations have not been made. I do insist, however, that the United States and the global technological landscape would be vastly different in the absence of United States military and defense-related contributions to commercial technology development.

An answer to the question posed in the title to this article requires a response to two additional questions. One is whether military and defense related research, development and procurement will continue to be an important source of commercial technology development. During the first two post-war decades it was generally taken as self evident that substantial spin-off of commercial technology development could be expected from military and defense related R&D. The slowdown in United States productivity growth beginning in the early 1970s raised substantial question about this assumption.

In 1993 Deputy Secretary of Defense announced an end to the dual sourcing policy that had helped maintain a semblance of completive structure in the defense industries. By the end of the 1990s it was becoming clear that changes in the structure of the U.S. economy and of the defense industrial base, particularly consolidation in the defense industries, had induced substantial skepticism that military and defense related research, development and procurement could continue to play an important role in the generation of new general purpose technologies. I argue that defense and defense related research, development and procurement is unlikely to represent an important source of new general purpose technologies over the next several decades.

A second issue is whether the private sector can be relied on as a source of major new general purpose technology development. The quick answer is that it cannot! Each of the general purpose technologies that I have reviewed has required at least several decades of public support to reach the threshold of military and commercial viability. Decision makers in the private sector seldom have access to the patient capital implied by a time horizon measured in decades rather than years. Many of the older research intensive private firms such as Bell Telephone Laboratories and RCA have almost completely withdrawn from the conduct of basic research and even from early stage technology development.

As each general purpose technology reaches maturity sustained economic growth will depend on the emergence of new general purpose technologies capable of generating growth dividends in the form of productivity growth. Studies by Robert Gordon and others have demonstrated that in the half century between 1910 and 1960 productivity growth generated by the electric light and power industries were responsible for approximately half of United States' productivity growth. Studies by Dale Jorgenson and colleagues indicate that computers, semiconductors and related information technology have, since the early1990s, accounted for approximately half of United States' productivity growth. As this technology matures sustained economic growth will depend on the emergence of new revolutionary productivity growth enhancing general purpose technologies.

When the history of U.S. technology development for the next half century is eventually written it is my sense that it will be characterized by endless novelty—on incremental rather than revolutionary changes in both military and commercial technology. It will also be written in the context of slower productivity growth than the rates that prevailed in the United States during the first several post-World War II decades and that have prevailed since the beginning of the information technology bubble that began in the early 1990s.

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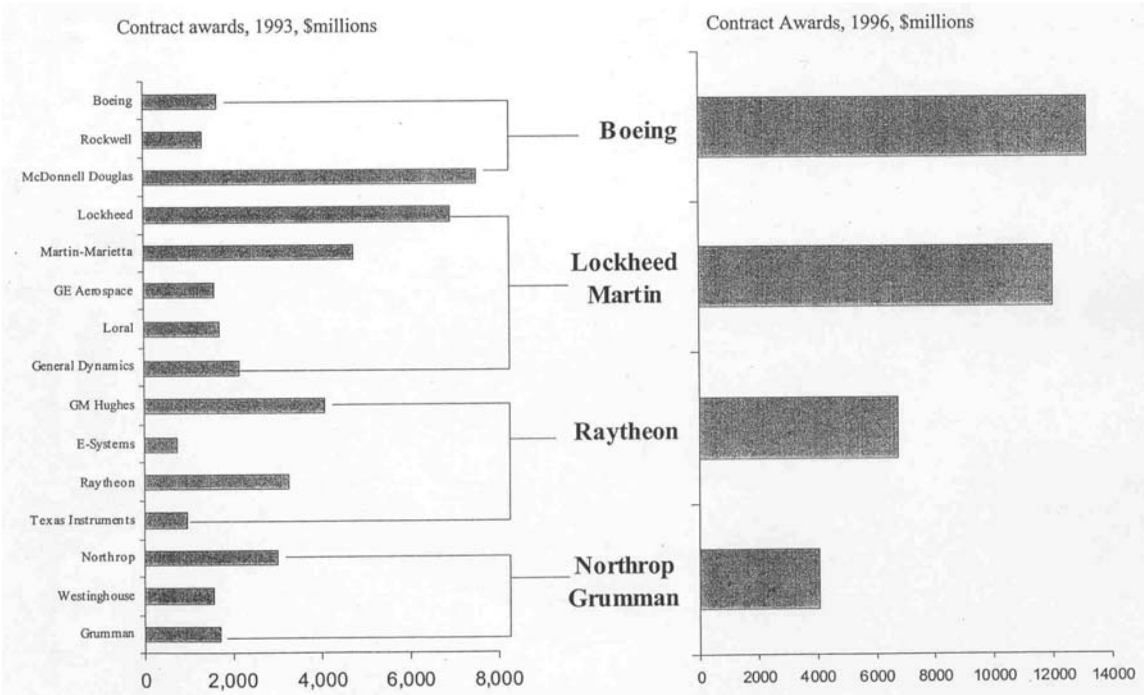
Figure 1. U.S. Defense Mergers in the 1990s



Source: Ann Markuson, 1998, "The Post-Cold War Persistance of Defense Spending," in *The Defense Industry in the Post-Cold War Era: Corporate Strategies and Public Policy Perspectives*, ed G. I. Susman and S. O'Keefe (Amsterdam). Reprinted with permission of Elsevier.