

CHAPTER 1

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CHAPTER I

INTRODUCTION

It is difficult to overemphasize the importance of the historical role that military procurement has played in the process of technology development. Knowledge acquired in making weapons was an important source of the industrial revolution. To bore the condenser cylinders for his steam engines “Watt had to turn to John Wilkinson, a cannon-borer, who had invented the one machine in all England that could drill through a block of cast iron with accuracy” (Kaempffert, 1941: 435). In France the navy provided the market that gave French entrepreneurs an opportunity to catch up with British advances in ferrous metallurgy (McNeill, 1982: 177, 211-212). In the United States what came to be termed the American system of manufacturing emerged from the New

England armory system of gun manufacture (Rosenberg, 1972: 87-116; Smith 1985: 39-86). During every year since World War II defense and defense related research and technology development expenditures have accounted for at least half, and sometimes as much as two thirds, of all U.S. federal government research and development expenditures (National Science Board 2004: A4 60).

WAR AND ECONOMIC DEVELOPMENT

The relationship between war and economic development has been controversial in economic history.¹ In *Krieg and Kapitalismus* (1913) Werner Sombart argued that in Western Europe war and the preparation of war gave rise to the economic institutions of capitalism (Smith, 1985: 29-30). In his classic work on *War and Human Progress*, John U. Nef argued, partly in response to the Sombart thesis, that the apparent association between war and economic development does not bear up well under careful historical analysis. Impressions of the impact of war

¹ In this section I have drawn on the exceedingly thorough review of the literature on the history of military institutions and social change by Barton Hacker (1994: 768-834).

on technical change are, for example, a result of the intensification of military procurement during war that draw on the accumulation of earlier advances in scientific and technical knowledge (Nef, 1950: 375-78; Mokyr 1990: 183-186).

This issue became a subject of heated debate in the U.S. in the 1960s. A study conducted by the Office of the Director of Defense Research and Engineering (HINDSIGHT) purported to show that the significant “research events” that had contributed to the development of 20 major weapons systems were predominantly motivated by military need (Sherwin and Isenson, 1967). This view was challenged in studies commissioned by the National Science Foundation and conducted by the Illinois Institute of Technology (TRACES) and Battelle Research Institute (1968, 1973). The TRACES and the Battelle studies adopted a much longer time horizon than the 20-year period employed in the HINDSIGHT study. These studies concluded that earlier science events, unrelated to military considerations, were of much greater

importance relative to technology events as sources of technical change (Mowery and Rosenberg 1979; Thirtle and Ruttan 1987).

During the Cold War defense and defense related R&D expenditures were criticized as a burden on rather than as a source of productivity growth. It was argued that defense and defense related research and technology development, by drawing scientific and technical capacity away from commercial application, had the effect of slowing technical change in industry (Solo, 1962: 49-60; Melman 1974; Dumas 1980; Kaldor 1981; Lichtenberg 1989).² In addition U.S. industry has been criticized for being slow to take advantage of the technology transfer opportunities resulting from military and defense related R&D. Defense contractors often insulated their military and defense related R&D from their commercially oriented R&D (Lichtenberg,

² For a thorough review of the literature on military expenditures and economic growth see Sandler and Hartley (1995). Sandler and Hartley are critical of much of the literature for emphasizing either supply-side or demand-side effects of military procurement expenditures.. In attempting to understand the effects of defense expenditures on economic growth, “the researcher needs to account for the supply-side influences (e.g. technology spin-offs and positive externalities from infrastructure) and the demand side factors (e.g. the crowding out of investment or of exports” (Sandler and Hartley 1995: 202-203).

1989; Alic et al. 1992: 43-44; Markusen and Yudken, 1992: 69-100).

In a landmark book published in the mid-1980s, *Military Enterprise and Technological Change*, Merritt Roe Smith, a leading historian of technology, complained that economic historians had largely neglected the contribution of military research, development and procurement on the development of commercial technology (Smith, 1985: 32-37). In my recent book, *Technology, Growth and Development* (Ruttan, 2001), I gave considerable attention to the role of the U.S. public sector in the development of major general purpose technologies.³ I discussed several examples but did not give particular attention to the role of military and defense related procurement as a source of commercial technology development. The issue was sitting there in plain sight but I was unable or unwilling to acknowledge it.⁴

³ General purpose technologies exert a pervasive impact across a number of industries. A consistent feature in the history of general purpose technologies has been a lengthy period between their emergence and their impact (David 1990; Lipsey et al. 1998).

⁴ I have not been alone in finessing the role of military procurement in technology development. Members of the scientific community have often preferred to avoid discussion of the intimate relationship between their own research and government investment in military technology (Forman and Sanchez-Rom 1991).

The purpose of this book is to demonstrate that military and defense related procurement has been a major source of technology development across a broad spectrum of industries that account for an important share of U.S. industrial production. I use the term military and defense related procurement broadly to include the research and technology development (including design) conducted by the military services in their own research organizations, by other federal government defense related agencies, and by contractors that conduct research and development in connection with military and defense related procurement.

I am interested in military and defense related technology development primarily to the extent that it contributes to commercial technology development. And I am concerned with the impact of military and defense related technology development on commercial technology development primarily during the early

In contemporary public policy discussion reference is frequently made to the government role or to government support when the military research and development or military and defense related procurement would be more precise. See, for example, National Research Council (1999).

stages in which commercial technology has most typically drawn on military and defense related research and technology development. As a field of commercial technology that initially drew heavily on military R&D or military and defense related procurement matures its dependence on military and defense related sources tends to decline. The flow of knowledge and technology may then reverse—“from spinoff to spinon.” I focus primarily on the United States. Since the end of World War II the United States has played a predominant role in initiating or implementing the new general purpose technologies that have emerged from military and defense research and development and defense related procurement.

In this book I focus on six general purpose technologies: (1) interchangeable parts and mass production, (2) military and commercial aircraft, (3) nuclear energy and electric power, (4) computers and semiconductors, (5) the internet and (6) the space

industries.⁵ In a concluding chapter I address the role of military and defense related procurement on technology development in the United States in a post industrial economy.

The chapter on interchangeable parts and mass production is included to illustrate that the role of the military in U.S technology development extends back to the early years of the nation. In each chapter I speculate, in the spirit of counterfactual analysis, on whether, in the absence of the stimulus resulting from military procurement, commercial development would have occurred “anyway” —or at least more slowly.⁶

In the next section of this chapter I present an overview of the theoretical perspectives that have guided economists in their attempts to understand the economic forces that have influenced

⁵ Other areas in which military R& D and military and defense related procurement have played a significant role in technology development include the laser, radio, food processing, chemical and medical industries. I do not, in this book, discuss the large number of secondary spin-offs from military and defense related research and procurement. A classic example is the microwave oven, a spin-off from research on radar, developed by Raytheon. Popular accounts of spin-offs from military and space research and procurement have often been excessively extravagant or wholly fictitious (Alic, et al. 1992: 54-81).

⁶ Counterfactual analysis became a central concern in the “new economic history” introduced by a younger group of economic historians in the late 1950s and 1960s. As practiced by the new economic historians counterfactual analysis involved the application of economic theory and econometric method to establish the effects of technical and institutional innovations on the course of economic development. The net effects of technical and institutional change on development involves “a comparison between what actually happened and what would have happened in the absence of the specified circumstances,” Fogel 1966: 653). The introduction of formal analytical-quantitative methodology became a source of substantial debate among economic historians in the 1960s (Fogel 1967). The counterfactual arguments in this book are based on traditional narrative rather than econometric analysis.

the rate and direction of technical change in commercial technology development. Throughout the book I will explore the extent to which these theoretical perspectives illuminate the sources of military and defense related technologies. In a final section of this chapter I present an annotated chapter outline of this book.

RATE AND DIRECTION

Historians of science and technology, and scientists and engineers themselves, have traditionally sought to interpret advances in scientific and engineering knowledge internally--in terms of the motives of individual scientists and engineers or in terms of the culture of scientific and engineering societies and communities, rather than in terms of changes of differences in social, political and economic environments. Internalist interpretations have become considerably less compelling as advances in scientific and engineering knowledge have increasingly emerged from large government and industrial laboratories and from contract research

carried out at major research universities. They have however retained substantial currency in military history (Hacker 1994). Edward Constant has however insisted that “the micro processes governing the evolution of military technologies is no different than any other technology.”⁷

The 1960s through the 1980s were very productive of the development by economists of new theory and new insight into the sources of technical change. In the 1960s and 1970’s attention focused on the development and testing of the theory of induced technical change— particularly on the role of economic forces, primarily changes in demand and changes in relative factor prices, on the rate and direction of technical change. In the late 1970s and early 1980s attention shifted to evolutionary models inspired by a revival of interest in Schumpeter’s work on the sources of economic development. Beginning in the early 1980s these theories have been supplemented by the development of

⁷ I have reviewed the evolution of thought on the sources of innovation in scientific and technical knowledge in Ruttan (2001: 63-99, 534-538; Ruttan 2003: 82-87) and on the rate and direction of technical change in Ruttan (2001: 100-146).

historically grounded “path dependent” models of technical change. Each has contributed substantial insight into the process of the generation and choice of new technology

Induced Technical Change

In a now classic study of patent statistics Jacob Schmookler (1950) showed that in the United States over much of the 19th century when investment rose capital goods inventions also rose; when investment declined the flow of patents declined. His intensive historical studies of a series of major inventions led him to conclude that demand was a more important source of change in the *rate* of technical change than advances in the state of knowledge (Schmookler 1963, 1966).⁸

Arguments about the relative importance of “demand side” and “supply side” forces intensified in the late 1960s. I referred above to a study conducted by the Office of the Director of Defense Research and Engineering that purported to show that significant “research events” that contributed to the development

⁸ The Schmookler work initiated an intense debate among economic historians on the relative importance of “demand Pull” relative to “supply push” as a source of technical change (Mowrey and Rosenberg 1979).

of 20 major weapons systems were motivated primarily by military “need” rather than by disinterested scientific inquiry (Thirtle and Ruttan 1987: 6-11). Subsequent studies have shown that technical changes induced by both supply and demand side factors have played an important role in the life cycles of many industries (Walsh 1984: 233). But there should be no argument that growth in demand does represent a powerful inducement to the allocation of resources to research and that military procurement has been an important source of demand induced technical change.

Interest in the effects of changes (and differences) in relative factor endowments and prices on the *direction* of technical change was initially stimulated by an observation by Sir John Hicks: “The real reason for the predominance of labor saving innovation is surely that ... a change in relative prices of factors of production is itself a spur to innovation and to innovation of a particular kind—

directed at economizing the use of a factor which has become relatively expensive” (Hicks 1932: 124-125).⁹

The first econometric tests of the micro-economic theory of induced technical change were conducted by Yujiro Hayami and Vernon W. Ruttan against the history of technical change in agriculture in the United States and Japan (Hayami and Ruttan 1973; 1985). It was apparent that the enormous changes in land-labor ratios over time in the two countries could not be explained by simple factor substitution. Hayami and Ruttan showed that (1) land and mechanical power were complements and mechanical power and labor were substitutes and (2) fertilizer and land infrastructure were complements and fertilizer and land were substitutes. Their econometric tests confirmed that the enormous changes in factor proportions that occurred in the process of development in the two countries represented a process of dynamic factor substitution in response to technical change induced by changes in relative factor endowments. Japan initially followed a

⁹ The theory of induced innovation, particularly its macro-economic variant, was the subject of considerable controversy in the mid 1960s. For a review see Nordhaus (1973).

“biological” and the United States a “mechanical” technical trajectory. Since the middle of the 20th century the trajectories have experienced substantial convergence.

The Hayami-Ruttan work was followed by a large number of empirical tests of the microeconomic version of the induced technical change hypothesis in the agricultural, natural resource, and industrial sectors (Thirtle and Ruttan 1987). The results of these tests confirmed that changes (and sometimes differences) in relative factor endowments and prices exerted a pervasive impact on the direction of technical change. The only formal test of the induced innovation hypothesis against military procurement is the Ames—Rosenberg (1968) study of technical change in the Springfield Armory (United States) and the Enfield Arsenal (United Kingdom). They found that part of the explanation for the higher labor productivity at Springfield was to be found in the relative prices of raw materials (wood and metal) and in the wages of highly skilled workers relative to less skilled workers. It is hard to believe that the enormous rise in the price of labor relative to the

price of capital equipment in the United States economy has not played a significant role in inducing the capital intensity of U.S. military technology. Only an economy that places an extremely high value on human capital could devote resources to producing a tool as expensive as stealth aircraft.

Evolutionary Theory

Modern interest in an evolutionary theory of technical change derives largely from the work of Richard R. Nelson and Sidney Winter in the 1970's. A series of articles was followed by a highly acclaimed book, *Evolutionary Theories of Economic Change* (Nelson and Winter 1982).¹⁰ The Nelson—Winter evolutionary model jettisons much of what they consider the excess baggage of the neoclassical theory, including profit maximizing firm behavior and the production function as a description of firm level technology, which play a central role in the theory of induced technical change. The theoretical cornerstone of the Nelson Winter

¹⁰ Evolutionary theory has experienced substantial elaboration since its early articulation by Nelson and Winter. See particularly the review and comparison with neoclassical theory in Mulder (1994: 32-48).

model is the behavioral theory of the firm in which profit maximizing behavior is replaced by the concept of “routine”—a term that included characteristics that range from well specified technical *procedures* for producing things and for managing procedures and practices, research, and development, and business strategies about product diversification, investment and marketing (Nelson and Winter 1982: 14).

The two fundamental mechanisms in the Nelson-Winter models are the *search* for better techniques and the *selection* of firms or technologies by the market. The learning activities leading to technical change are characterized by (1) local search for technical innovations, (2) imitation of practices employed by other firms, and (3) “satisficing” economic behavior. Search for new technology, whether generated internally by R&D or transferred from suppliers or competitors, is set in motion when profits fall below a certain threshold. A change in factor prices, a rise in the wage rate for example, will cause some techniques to fail the

profitability test and different techniques to pass the tests they might have failed at a lower wage rate.

History plays an important role in the Nelson-Winter evolutionary models. The condition of the industry in each time period shapes its condition in the following period. “Some economic processes are conceived as working very fast, driving some of the model variables to temporary equilibrium values within a single period ... Slower working processes of investment and technological and organizational change operate to modify the data of the short run equilibrium system from period to period or even from instant to instant,” (Winter, 1984: 290).

The Nelson-Winter evolutionary models have provided very substantial insight into the operation of large bureaucratic firms, such as those in the aero-space industry, particularly in their approach to technical innovation. The pipeline model of military procurement (Chapter 8) is not unlike the process assumed in some of the Nelson-Winter simulations. I have not, however, been able to identify any empirical studies of the rate and direction of

military or defense related R&D that have attempted to use or test the Nelson-Winter evolutionary theory

Path Dependence

The argument that technological change is *path dependent* was vigorously advanced by W. Bryan Arthur and several colleagues beginning in early 1980s (Arthur 1983, 1989, 1994). In the mid and late 1980s Paul A. David presented the results of a series of historical studies—of the typewriter keyboard, the electric light and power industry and others—that served to buttress the plausibility of the path dependence perspective (David 1985, David and Bunn 1988).

The distinctive contribution of the work by Arthur, David and their colleagues was their emphasis of increasing returns to scale as a source of technical “lock-in.” In some non-linear dynamic systems positive feedbacks, termed *polya processes*, may cause particular technological patterns or structures to become self reinforcing. “Often there is a multiplicity of patterns that are

candidates for long term self-reinforcement. A combination of small events early in the R&D process pushes the dynamics of technical choice into the orbit of one of these paths and thus ‘selects’ the structure that the system eventually locks into” (Arthur 1994, 294). He cites the almost accidental dominance of personal computer software by Microsoft as an example (Arthur 1989: 127).

David has presented the dominance of the QWERTY (the first six letters on the left top row) typewriter and computer keyboard as a particularly compelling example of how an inefficient (from today’s perspective) technology was introduced and has persisted. David’s answer is that an innovation in typing method, touch typing, gave rise to three features that were critically important in causing QWERTY to become ‘locked in “as the dominant keyboard arrangement. These features were *technical interrelatedness, economies of scale, and quasi-reversibility of investment* (David 1985: 334). Technical interrelatedness refers to the need for system compatibility—in this case the linkage

between the design of the typewriter keyboard and the typists' memory of a particular keyboard arrangement. Economies of scale refers to the decline in the user cost of the QWERTY system (or any other system) as it gains acceptance relative to other systems. The quasi-reversibility is the result of the acquisition of specific touch typing skills (the "software"). These characteristics are sometimes bundled under the rubric of "network externalities."

The development of nuclear power for commercial use (Chapter 4) is an example drawn from defense related procurement. In the early 1950's the Atomic Energy Commission (AEC) initiated a program to support and evaluate alternative nuclear reactor designs. Before this evaluation was complete events conspired to force a choice of the light water reactor. One event was the choice by the U.S. Navy of the light water reactor for propulsion of its nuclear submarine. A second was President Eisenhower's desire for early implementation of nuclear power generation as a showpiece for his Atoms for Peace initiative. A third was the subsidies to General Electric and Westinghouse that

enabled them to enter the international market with turnkey light water reactors in time to preempt the alternatives being pursued by other U.S. firms and national governments.

RADICAL TECHNOLOGY

The six general purpose technologies that I discuss in this book can all be described as radical or revolutionary technologies. They all represented revolutionary departures from existing technological trajectories. While the three economic models discussed above provide substantial insight into the rate and direction of incremental changes in technology they do not address the sources of revolutionary new technologies.

An earlier generation of historians of technology viewed major inventions a result of transcendental insight—as due to the unique inspiration of the occasional genius who achieves advances in knowledge through the exercise of intuition (Ruttan 2001: 65-66). In a landmark book on the history of the turbojet revolution Edward Constant advanced the concept of *presumptive*

anomaly as a source of radical advances in technology (Constant 1980). “Presumptive anomaly occurs in technology, not when the conventional system fails in any absolute or objective sense, but when assumptions derived from science indicate either under some future conditions the conventional system will fail (or function badly) or that a radically different system will do a better job” (Constant 1980: 15).¹¹ Thus in the case of the turbojet insight derived from aeronautics in the 1920s created a presumption among a few aircraft engineers that over the longer term fundamental constraints would be confronted on the performance of the piston-propeller system of aircraft propulsion (Chapter 3). By the late 1930s it had become apparent to Dr. Marvin Kelly, Director of Research at Bell Telephone Laboratories, that the heat generation capacity of vacuum tubes would become a constraint on the development a more rapid telephone switching technology (Chapter 5)

¹¹The Constand presumptive anomaly model bears some resemblance to the theory of paradigm shifts advanced by Thomas Kuhn to explain discontinuities in the history of scientific theory (Kuhn 1970).

It is not necessary that the insight that gives rise to a perception of anomaly be derived from science. Advances engineering or agronomic knowledge may also give rise to presumptive anomaly. When a radical new engineering technology is envisaged it may be initially judged as less efficient than the system it is designed to replace. Furthermore, a radical new general purpose technology will generally, over time, do much more than perform existing functions more efficiently. It will make possible new functions that the technology it replaces could not perform (Aitken 1985: 7-12) Thus the electronic digital computer not only replaced tabulating and calculating machines but opened up the possibility of entirely new communications technologies (Chapter 5).

The presumptive anomaly and the three economic models of the sources of technical change each represent an element that may in the future be incorporated into a more comprehensive or general model of the sources of technical change. But such a model does not yet exist. Each has been useful in advancing our understanding

of the sources of technical change. In this book I draw on the several models as I attempt to understand the role of military R&D and defense and defense related procurement on commercial technology development.

THE BOOK PLAN

In the following chapters of this book I discuss the role of military and defense related procurement on the development of six general purpose technologies that played a decisive role in the development of the United States economy in the 20th century.

In Chapter 2, *Interchangeable Parts and Mass Production*, I trace the role of military procurement on the development, in the early decades of the 19th century, on what came to be known as the “American System of Manufacturing.” Economic historians have characterized the American System, or more appropriately the New England Armory System, as the assembly of complex products produced from individual interchangeable parts. Its first important application was in the manufacture of firearms at the

U.S. Army Harpers Ferry (Virginia) and Springfield (Massachusetts) armories. During the second half of the nineteenth century “armory practice” diffused to other branches of manufacturing such as sewing machine and bicycle manufacture. It emerged in its most highly developed form in the mass production of automobiles at the Ford Motor Company in the first two decades of the 20th century.

In Chapter 3, *Military and Commercial Aircraft*, I trace the intimate relationship between military and commercial aircraft development. The aircraft industry was unique among manufacturing industries in that a government research organization, the National Advisory Committee on Aeronautics (NACA) was established shortly prior to U.S. entry into World War I to conduct research on military and commercial aircraft technology and design. NACA was an important, and efficient, source of new knowledge and new technology for the military and commercial aircraft industries for four decades until it was absorbed into the National Aeronautics and Space Administration

(NASA) in 1958. NASA continues to be involved in almost every aspect of aircraft research and technology development.

In Chapter 4, *Nuclear Energy and Electric Power*, I trace the origin of the nuclear power industry to the World War II Manhattan Project that was organized to develop and build the atomic bomb. The demonstration of controlled nuclear fission at the University of Chicago Stagg Field on December 2, 1942 initiated the chain of events that led to the development of nuclear power. Since the very beginning it has not been possible to understand the development of the nuclear power industry apart from the application of nuclear energy in military technology. The design of the first U.S. Nuclear power reactor, located at Shippingport (Pennsylvania) was adapted from nuclear reactors developed in the early 1950s to power nuclear submarines. This early commitment to the light water reactor design appears in retrospect to have been a source of the failure of the nuclear power industry to realize the promise that it appeared to have in the 1950s.

In Chapter 5, *The Computer and Semiconductor Industries*, I trace the development of the computer industry from the first all-purpose electronic digital computer developed by John W. Mauchly and J. Prosper Eckert and their associates at the University of Pennsylvania's Moore School of Electrical Engineering with funding from the U.S. Army ballistic Research Laboratory. The first working transistor emerged from the solid state research led by William Shockley, John Bardeen and Walter Brattain at Bell Laboratories in the late 1940s. The transition between the initial development of the transistor and the subsequent development of military and commercial application in the 1950s was substantially funded by the Army Signal Corps.

In Chapter 6, *Inventing the Internet*, I trace the role of the Defense Advanced Research Projects Agency (DARPA) from the initial interest of its Information Processing Techniques Office in man-machine interaction in the early 1960s to the development of a project to interconnect large computers at a number of academic, industrial and government computer centers in the early 1970s

through the invention of the INTERNET and its eventual privatization. It was not until 1990 that military responsibility for the INTERNET was finally terminated.

In Chapter 7, *The Space Industries*, I trace the implications of the charge, in the Space Act of 1958, of the National Aeronautic and Space Agency (NASA) with responsibility for ensuring U.S. leadership in space technology, including weather, communications and remote sensing satellites, important to national prestige, national defense and foreign policy. NASA played an early entrepreneurial role in the development of both communications and earth observing satellites for military and commercial purposes. In the last several decades development of civil applications were slowed by national security considerations and by ideologically burdened privatization policies that threatened economic viability.

In a final chapter, *Military Procurements in a Post Industrial Economy*, I address several issues that bear on the impact of military and defense related procurement on technology

development in the United States in the future. *One* is whether changes in the structure of the American economy preclude military procurement from playing the important role in the development of advanced technology in the future comparable to that it played in the past. It has been argued that in many areas of technology the direction of spin off in recent decades has shifted from commercial to military rather than from military to commercial technology. A *second* related argument is that the military and defense related industries have become so small relative to the size of the United States economy, or even of the manufacturing sector, that it no longer exerts significant leverage on the rate or direction of technical change (Nelson and Wright 1992; Alic et al. 1992).

If the answers to the above question are positive—if military or defense related procurement remain essential sources of advanced technology development it raises a *second* and even more disturbing question. Will war, or at least the threat of war, continue to be necessary to induce the “political will” to mobilize

the scientific, technical and financial resources to generate new general purpose technologies? I will return to this issue in the final chapter.

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