New England Journal of Public Policy

Volume 2 | Issue 1 Article 3

1-1-1986

War Stories--Defense Spending and the Growth of the Massachusetts Economy

David L. Warsh

War Stories—Defense Spending and the Growth of the Massachusetts Economy

David L. Warsh

The defense industry has been an integral part of the Massachusetts economy since colonial days, and the Watertown Arsenal and Springfield rifle are virtually synonymous with the capital-intensive arms business of the nineteenth century. But after World War II, here as elsewhere, defense production became far more deeply embedded in the state's division of labor, with the result that today it is hard to tell what is of military origin and what is not: the minicomputer and software industries, in their entirety, are properly viewed as a spin-off from the Cold War and the space race, for example. The region's unique claim on these downstream effects of military spending stems partly from Yankee ingenuity, mostly from a highly developed educational establishment and an influential political delegation to Congress. These institutional matrices are also the chief strongholds of Massachusetts's traditional antimilitary liberalism, an arrangement which gives rise to many paradoxes, but wisdom begins with an appreciation of just how intricate and powerful and resistant to challenge is the military industrial complex itself.

Boston's arsenal has a long and significant history. Its ropewalk, shipyards, foundries, armories, and powder factories were among the first in the western hemisphere; they date from the city's deep involvement in the global contest between the English and the French that began in 1689 with King William's War and ended only 125 years later with the defeat of Napoleon.[1] Many nodes have developed in the American defense industry over 300 years, but Boston, like Virginia, has kept its franchise. The powder business went to Delaware; shipbuilding went to satellite ports in New England; military outfitting went south with the textile mills; the rope business went to Iowa; even naval rifles eventually went elsewhere; but New England found new products and new niches.

If Chicago and Los Alamos gave the nation nuclear weapons; if Los Angeles gave it airframes and rockets; if its submarines came mostly from Virginia; if Maryland supplied germs and spies; if the space franchise went to Texas and Florida; then it was here, in New England, that command and control of the new war machine evolved; here that significant strands of radio, radar, sonar, engines, missiles, instrumentation, telemetry, and satellite photography were developed. Even the possibility of a retail trade emerged: it was at a little plant in Salem that agents for Pakistan

David Warsh is the author of The Idea of Economic Complexity *and covers economics for the* Boston Globe.

sought in 1983 to buy a supply of krytons, electronic switches that can serve as triggers for its nuclear bombs.[2] Yet it was from a small office above Sparr's Drug Store, in the center of Boston's medical-school ghetto, that the International Physicians for the Prevention of Nuclear War organized the crusade that won it the Nobel Peace Prize last year, and this was only the most recent of many periodic attempts by organizations whose roots are in New England to diminish the influence of the military.

Anyone who thinks dispassionately will recognize that over the years the war business consistently has enlarged its sphere of operation in the city and the region that surrounds it, even as the business has become less visible. True, the Boston Army Base is being converted into an "international design center"; the navy's old Fargo Building is now an office building; the shipyard in Charlestown is a condominium complex for yuppies; the Watertown Arsenal is now a mall full of shops and restaurants. The antiwar movements that have found fertile soil here have been powerless to deflect the trend. The weapons laboratories' formal ties to universities may have been severed, but the effect of the severing has been largely cosmetic. The arms business in New England has been camouflaged by careful landscaping and a remarkable burst of growth in the region's ploughshare industries—first and foremost, the computer industry—but it is bigger than ever.

Let me say a word about the geography of the defense industry in New England, as I understand it. We think regionally because we think historically and politically: it is Congress, after all, which votes the appropriations for defense contracts. There was a time when each important city in the six New England states was a separate part of the military establishment, its special significance stemming from its proximity to a river: Hartford, Springfield, Boston, Portsmouth, New London, New Haven, Providence. Today, with the vastly altered realities of transportation and communication, to say nothing of the rise of modern corporate management, I believe it is better to think of Boston as the central locale and to regard other cities in New England as subordinate to it, at least in this connection, even though this occasionally does damage to the facts: Burlington, Vermont, for example, is an important beneficiary of military R and D spending on advanced computer techniques, but most of the revenue stream for these projects comes through New York City rather than through Boston. The really important exception is Hartford, which is a nearly independent entity. But for the sake of simplicity, in this article I treat Boston as though it were nearly synonymous with New England.

What is the role of defense in the economy of New England? How does the military economy work? How deeply is it embedded here? How did it grow? Is it good or bad for business? What are the chances that the hopes raised by peace movements of one sort or another will pan out? And what would be the consequences if they did? It is said by economists that New England does well these days because it is aloof from the problem industries: steel, autos, farming, energy; what will happen on that happy day when peace breaks out and the defense industry becomes a problem? We don't need to worry—not much—about the day the war breaks out. As my colleague M. R. Montgomery says, "One airburst over Minuteman National Park and you get rid of Lincoln Labs, Mitre, Itek, Bolt Beranek and Newman, the Peking Gardens restaurant, and the Daniel Chester French statue. One burst would get them all."[3]

The Military Industrial Complex

To think about these issues at all is to think about the military industrial complex itself. A quarter of a century has elapsed since President Dwight Eisenhower formally warned of its existence and of the dangers it posed, and his formulation has hardly been improved upon since. "Until the last World War, the United States had no armaments industry," he noted on January 17, 1961, speaking to a radio and television audience.

> But now we can no longer risk emergency improvisation of national defense; we have been compelled to create a permanent arms industry of vast proportions. Added to this, three and a half million men and women are directly engaged in the defense establishment. We annually spend on national security more than the net income of all United States corporations.
>
> This conjunction of an immense military establishment and a large arms industry is new in the American experience. The total influence—economic, political, even spiritual—is felt in every city, every State House, every office of the federal government. We recognize the imperative need for this development. Yet we must never fail to comprehend its grave implications. . . . Only an alert and knowledgeable citizenry can compel the proper meshing of the huge industrial and military machinery of defense with our peaceful methods and goals, so that security and liberty may prosper together.[4]

Perhaps the most striking fact of the matter is that, except for the years of the Vietnam War, the role of the military in national life has diminished since Eisenhower's time, despite—or perhaps because of—his warning. Take a look at figure 1. It shows that military spending, as a proportion of the gross national product, declined from around 10 percent when Eisenhower left the White House to just under 5 percent midway through the presidency of Jimmy Carter, before climbing back to what it is today, a shade over 6 percent. The finer points involved in determining these numbers are a matter of some controversy among experts, of course, but the broad shape of the trend is not in dispute.

To be sure, the number of dollars involved and the sheer destructive power that they purchase are more formidable than ever. Eisenhower's biggest budget totaled $95 billion. In the budget submitted to Congress this past January, President Reagan requested $312 billion for defense alone and said he planned to spend around $274 billion—some 28 percent of the entire federal budget, or 6.2 percent of GNP. The price of maintaining the defense establishment is all the more overwhelming if calculated, as Eisenhower did, in terms of opportunity cost: one Arleigh Burke destroyer is worth two big-city hospitals, and one Bradley tank is worth a good suburban school. Yet the fact is that as America has grown rich in the long postwar boom, it has been able to spend less of its income on defense and more on other items, notably health care, where the trend has been just the reverse: in 1965, health care consumed 6.1 percent of U.S. GNP; in 1975, 8.1 percent; and in 1983, 10.8 percent.

If you want to contemplate what has happened with the defense establishment since 1960, go to the main floor of Sidney Kramer's bookstore in Washington, D.C., one block from the White House. This is in many respects the most remarkable bookstore in the world. Its inventory is limited to a few policy-oriented tastes, but within each of these specialties, it offers an utterly comprehensive selection of books

Figure 1

Note: Figures for 1986 and 1987 are estimated.

Source: Tim Carrington, "Call for 12% Increase in Pentagon Funds Faces Almost Certain Defeat in Congress," *Wall Street Journal*, 6 February 1986, 8.

in print. An entire wall is devoted to current books about the military, ranging from World War II porn to the most erudite tracts on strategic issues; on the wall opposite is an even larger array of books devoted to portraying the world economy that has grown up around its armies. The military, like nearly everything else under the sun, has become increasingly complex, specialized, and intricate. Yet except for a few durable classics more notable for the labels they contributed to the debate than for their analysis—C. Wright Mills's *The Power Elite,* for example, or John Kenneth Galbraith's *The New Industrial State*—there are few titles that deal with the historic growth of the military industrial complex. There are some good essays by independent scholars like Jacques Gansler[5] or James Fallows.[6] There are a number of studies by professional historians of technology that make promising beginnings; a good place to make their acquaintance is an anthology by M.I.T.'s Merritt Roe Smith, *Military Enterprise and Technological Change,* with its bibliography on technology and war by Alex Roland.[7] But economists for the most part have ducked the issue of the role of the military in the national economy, mainly because the large institutional forces at work don't submit easily to the primary tool of the economics trade—the analysis of equilibrium in well-ordered markets.

In real life, however, it is institutions that make economic history. Families, firms, corporations, industry associations, regions of nations and alliances of nations all make tricky decisions to enter into complicated coalitions, thinking forward and backward in time. These arrangements blend financial decisions, tax considerations, design criteria, research and development support, and many other stratagems, subtle and not so subtle, to load the dice in certain ways. Almost always, they involve intricate—if wary—alliances between business and government. Many of these loose legislative-industrial associations have figured prominently in the nation's history: the water and real estate interests that developed southern California, for instance; the electricity lobby, both before and after the advent of nuclear power; the oil, highway, and auto complex that overtook the electrical utility-mass transit network; the builders, bankers, and legislators who created the basis for the postwar housing boom. These "complexes" are not figments of the imagination; they are no less powerful for being little understood. The health complex is perhaps the other truly dominating feature of the landscape today, and by total resources as a percent of GNP, it is nearly twice as large as the defense establishment. But it is highly fractionated. The military industrial complex is the biggest, most fully integrated single unit in the economy.

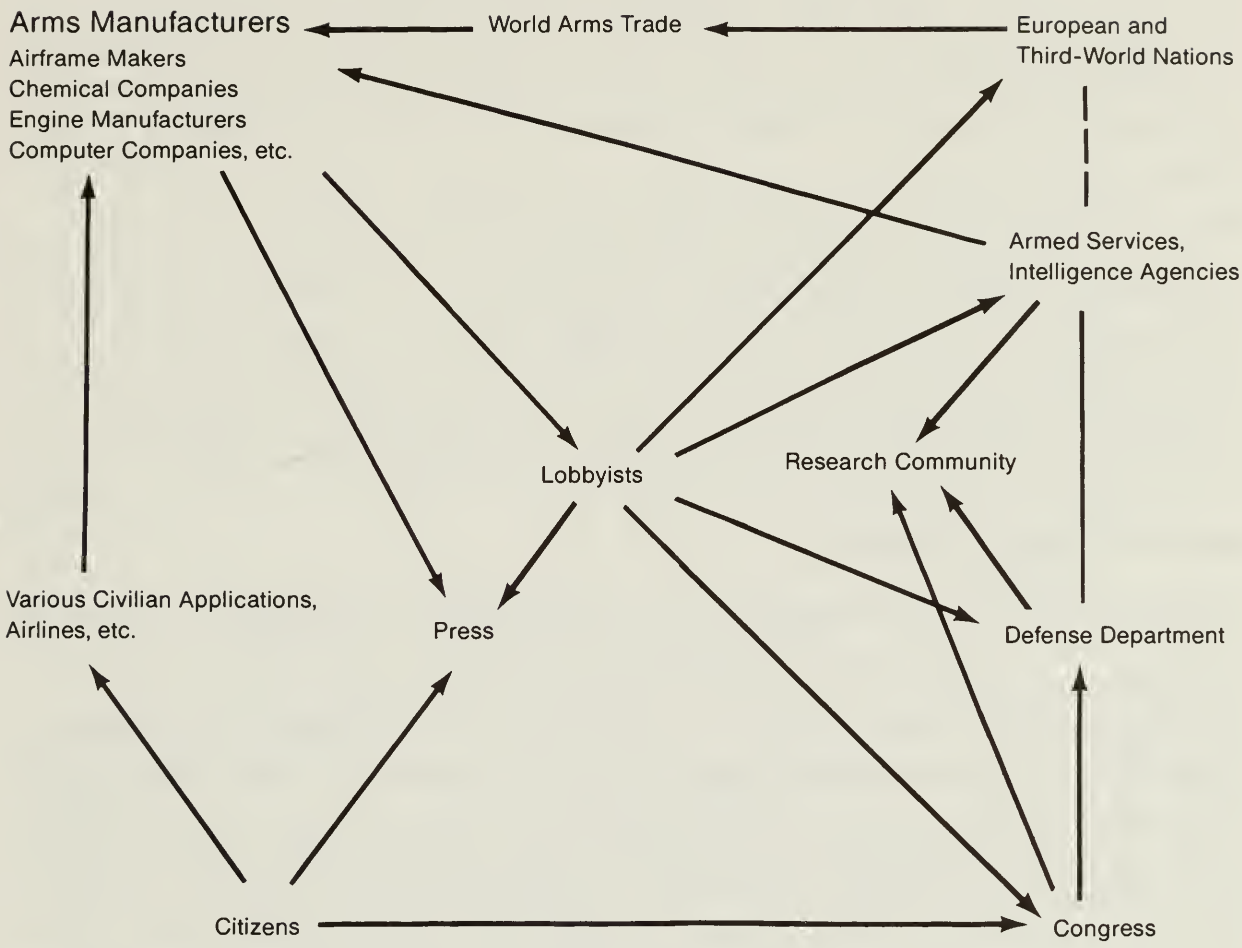
How Things Hang Together

For a stylized glimpse of the composition of the military industrial complex, take a look at figure 2, which is titled "Weapons Industry Cost Web." This is a manner of representation I devised some years ago; it's modeled on the food webs that ecologists use to demonstrate who eats whom in particular communities of living things.[8] The idea is to show the relationships among the groups of people who choose to incur the costs of military defense and who must in turn bear them. All the familiar features of the landscape are here, along with some that may not be so familiar. Note, for example, the prominent role of the Third World arms trade: this is a crucial aspect of the arms business, because economies of scale that arise during long production runs are vital to profitability (see Anthony Sampson's *The Arms Bazaar*). Note, too, the civilian businesses of the weapons makers: the commercial airplanes, the computer manufacturers, and so on (see John Newhouse's *The Sporty Game*).

It was clear by Dwight Eisenhower's time that the internal dynamic of the military-industrial complex could cause large sums of money to be spent unwisely, and it became even more clear as time went by. Much of Robert McNamara's tenure as secretary of defense was spent trying to tame the procurement process—yet the process remains untamed. There are many fine investigations of the pathology of inter-service rivalry, from the TFX decision to the C5A scandal to the B-1 bomber. And there is every reason to believe that this process is susceptible to at least some correction. Is it ironic that President Reagan is so tough on the federal budget generally, yet so permissive where the Pentagon is concerned? "Let's face it," he said this past February, "there's a ton of fat in this trillion-dollar government."[9] Does he think there is no fat in the military? Presumably not. But he and Defense Secretary Weinberger seem driven by the logic of overall share of GNP, by the conception of a long cycle of boom and bust in military spending. They are determined to get military spending

Figure 2

Weapons Industry Cost Web



Source: David Warsh, *The Idea of Economic Complexity* (New York: Penguin Books, 1985)

back to historic levels of around 6 percent of GNP before the cutting sets in again.

It would be helpful to articulate cost webs like the one in figure 2, to assign values to them, to compare them to other systems. Sharper resolution would be helpful, too. Many crucial units are too small to be listed here: the Defense Advanced Research Projects Agency (DARPA), which plays a part later in our story; or the intelligence agencies like the CIA, the National Security Agency, and the Defense Intelligence Agency; or the strategic theorists who hammer out the Single Integrated Operational Plans (SIOPS) that guide our policy.[10] Real policy tends to be made in even smaller groups, formal and informal: the interagency breakfast groups in Washington; the so-called Conquistadores del Cielo, the group of aerospace chief executives who meet to play cowboy each summer in Wyoming; the LIDOS, or Litton Industry Dropouts, who formed their views as rivals under Litton boss Tex Thornton and who later changed the face of the industry—United Technology's Harry Gray in particular; the battalion commanders who passed through the best divisions in Vietnam. These are the levels at which changes occur.

The element that is perhaps most key to understanding the overall behavior of the military-industrial complex—or the behavior of any "complex," I suppose—is altogether omitted from the cost web in figure 2. It is the external challenge—or, to put it a little differently, the end to which the product in question is consumed. The external challenge to the wheat industry is the hunger of the bread buyer; in medicine, the external challenge is death, disease, prevention, and so on. In the military case, it is the statecraft of enemy nations. The fear of Soviet expansion has been the driving force of U.S. military development since World War II, after all. It should go without saying that the principals of a system become adept in the manipulation of the most primitive fears involved here, often for their own purposes. Could the space race have been run without Sputnik? (See *The Heavens and the Earth,* Walter A. McDougall's account of the political dimension of the space race.) Yet it seems clear to me that the Cold War has not been entirely a matter of manipulation—even though I know there are many people smarter than I who would argue otherwise. Perhaps there is no more important function than assessing the other side's intentions and order of battle. I thought about drawing in this aspect of large technological systems to emphasize the nature of the overall system, but you've got to tear the web somewhere.

Sump? Or Engine of Progress?

The most basic debate concerns the elemental economic effects of military spending on the national economy—and therefore on the economics of the Bay State. These are familiar arguments. At one end of the spectrum there are those who say that defense spending is a sump, an utter waste of money, destructive at worst, unproductive at best. At the other end are those who say that the arms race can be highly stimulative, at least often, and that spin-offs and spillovers from military spending to the civilian economy are far from trivial. But those who take this position quickly divide into optimists and pessimists over the effects of these spin-offs and spillovers. In the latter part of this essay, I will present an episode against which these arguments can be intuitively measured, a case study of how military spending in the 1940s and 1950s prepared the way for a major industrial expansion in the 1960s, 1970s, and 1980s.

Fairly typical of proponents of the sump argument is Josh Weston, a New Jersey computer executive who tours the country on behalf of Business Executives for National Security, a 3500-member organization of liberal businessmen. Weston last year told the *Globe*'s Mark McCain: "We need to correct a popular misinterpretation that Pentagon spending helps the economy, prevents recessions, and creates vast numbers of jobs. In reality, our investment in defense spending is much more a common sacrifice than a boon to the economy. There are much better ways to spur the economy."[11] A somewhat fuller expression is to be found in the work of Emma Rothschild, who wrote in the *New York Review of Books* in 1980, "The United States may buy itself two things with its $1 trillion defense budget of 1981 to 1985. The first is an economic decline that comes once or twice in a century. The second is nuclear war."[12] The most pointed case of all has been developed over thirty years by Seymour Melman, a Columbia University professor. He says that the military system has been wrecking the economy ever since World War II.[13]

What these analysts agree on is that military spending retards natural growth, either by siphoning off precious talent or by soaking up capital, or both. Lester Thurow has suggested that the Japanese computer industry will drive the U.S. computer industry out of business because of Star Wars; it may be more fun to design a laser guidance system, but it is more profitable to design a toaster, he says.[14] Melman makes much, as Eisenhower did, of the sheer size of outlays, greater every year than the net profits of all U.S. corporations. In *Profits Without Production,* published in 1983, he wrote: "That military outlay, making up the largest single block of the economy's equivalent capital funds, makes no contribution whatever to the economic product of the society."[15] The effect of its subtraction is masked, he says, by an economic ideology that insists on counting military output as part of GNP: the GNP numbers get bigger and bigger, but the productive capacity of the nation gets smaller and smaller.

These sump arguments, it seems to me, can be dismissed out of hand, at least in their grander forms, for reasons that will become increasingly clear as we look at the composition of postwar boom. The world has been enjoying an enormous expansion of its productive capacity since 1946, a boom reaching into every corner of the world economy. The international division of labor has advanced rapidly; world markets have emerged in everything from steel to automobiles to electrical equipment—to the disadvantage of the industrial nations, which have coped by finding ever-more complicated products to sell in world markets. They have "moved higher up the value-added chain," as economists put it. All the while, military spending has consistently declined in relative terms—that is, as a portion of the whole—even as it has increased in absolute terms. If the military really is acting as a brake on development, one can only wonder at what would have been the case without it.

The military role in postwar growth has been indisputably stimulative, whether in plastics, airplanes, computers, communications, or pharmaceuticals, let alone high-energy physics. Wartime mobilization had far-reaching effects on corporate organization and planning activities; it had a pervasive effect on values in the civilian sphere as well. Time and again, the military has furnished the money for improbable leaps forward in technology, acting in effect as a clumsy industrial planner. It was the National Defense Highway Act that built the interstate road system, after all. There is much to be said for Seymour Melman as an analyst of the little loops and eddies of defense spending, but overall, his arguments fail to convince. The sump theory is a preserve of quacks, political activists, and well-meaning cranks. Most analysts agree that some form of technological pump priming is at work, with a substantial economic effect in the form of spin-offs and spillovers, as well as a general pumping up of demand: "military Keynesianism," it is often called.

Increasing Liberty? Or Iron Cage?

It is not that agreement about the nature of this hothouse effect holds up for very long; no consensus does, it seems, when it comes to the place of war in human history. Perhaps not since Werner Sombart published *War and Capitalism,* just before the outbreak of World War I, has anyone managed to sound genuinely optimistic about the relationship between war and economic growth. Today, the argument seems to be over whether military spending can be considered an engine of economic growth, never mind "progress," or whether it should be seen as something more sinister, the gradual extension of various forms of unwelcome social control over human life, a "progressive lessening of democracy, and an increase of . . . authoritarian technics," as Carroll W. Pursell, Jr., has put it.[16]

The "dark-siders"—the phrase was coined by historian Brooke Hindle to distinguish those "who counted the ways in which humanity had been submerged and subjugated" by the new machines from those who have emphasized the exhilaration of technology among consumers as well as purveyors[17]—comprise a sophisticated and imaginative group of critics, many of them with ties to M.I.T.: Michael Piore and Charles Sabel, Joseph Weizman, Langdon Winner, Harley Shaiken, and Emma Rothschild are among them. Many other critics have been drawn from the ranks of professional historians of technology. It is David Noble who has taken the sinister spillover interpretation to its extreme. In his remarkably interesting book *Forces of Production,* he argues that a military and managerial preoccupation with the control of worker conduct on the factory floor, conceived during the labor struggles of the 1930s, led to the economically unjustified development immediately after World War II of numerically controlled (i.e., computer-driven) machine tools. According to Noble, the result was that American managers and their military allies won victory over the craft unions but lost the international market for machine tools to the Germans and the Japanese.

In the other, rather more optimistic camp is most everybody else. Numerically controlled tools haven't found their Homer yet, but there are many other chronicles that tell the story of technological change with other processes, usually economic and intellectual, at its heart. Usually they make it clear why the events in question were called "progress." Perhaps the model is Thomas Hughes's extraordinary accomplishment, *Networks of Power,* a book that describes the evolution of modern electric power systems in the three quite different political environments of Berlin, Chicago, and London. There is David Hounshell's account of the exhaustion by Henry Ford of the possibilities of the long production run in *From the American System to Mass Production.* Or take Alfred Chandler's remarkable study of the invention of the corporate executive committee in *Pierre S. Dupont and the Making of the Modern Corporation,* or Nathan Rosenberg and L. E. Birdzell's *How the West Grew Rich,* in which they relate (among many other things) how Andrew Carnegie made his money by driving down the cost of steel by 88 percent over twenty-five years, and how John D. Rockefeller reduced the cost of kerosene by 66 percent in three years. Have the last fifty or one hundred years really been a big mistake?

A key distinction: often the pessimists see industry as learning virtually everything from war. They also tend to see military organization coming to dominate civilian life, as Lewis Mumford occasionally insisted it would. Optimists like Alfred Chandler see the corporations as quite a distinct form of organization, and the military as more often than not learning from the civilian sphere. This seems to me to be generally much closer to the facts. I can't forbear noting that most of the pessimists are not veterans of military service; only someone without firsthand experience in the military could attribute to its leaders the omniscience and articulate will that are articles of faith with, say, David Noble.

Still, this argument between the technological optimists and pessimists among the military Keynesians is much harder to gauge than the disagreement between them and those who deny that military enterprise has often had a stimulative effect. The image of the fifteenth century as a golden age of labor, of jolly yeomen treating each other well in preindustrial America, of alienation merely being a shadow on the horizon, seems a bit much to me.[18] To restate the question: Is the history of technological innovation, as driven by the military, an ultimately cheerful story of "the interaction of fortune, intellectual climate, and the prepared imaginative mind," as the optimist Elting Morison would have it? Or was the pessimist Lewis Mumford correct when he said the “murky air of the battlefield and the arsenal” hangs over the postwar world?[19] Here we will benefit from a closer look. Let us examine Massachusetts's chief legacy from the post–World War II arms race.

Computers: A Case in Point

It has long been a commonplace that the Cold War and the space race were not especially productive of the kinds of spin-offs generated by World War II. Nose-cone ceramics for baking dishes, Teflon for frying pans, microwave ovens, and a few other trivial consumer-oriented items were all we got for the billions we spent—or so the story goes. This is, to put it simply, a completely mistaken interpretation. The main spin-off of the Cold War was the computer; the main spillover of the space race was the semiconductor; and the economic ramifications of each are still reverberating throughout the world economy.

(I should note that what follows is not yet in any sense a commonly accepted version of events. The advent of computers is altogether left out of Merritt Roe Smith's book *Military Enterprise and Technological Change;* it is not even mentioned in the volume's bibliographic essay. Computers are all but ignored, too, in Walter A. McDougall's political history of the space race. The military origin thesis is not argued aggressively in the general histories of computers and semiconductors written by Stan Augarten, Joel Shurkin, T. R. Reid, and David Ritchie, though each author offers a wealth of detail to support the argument. Nor is the computer industry treated in Richard Zeckhauser and John Pratt's collection of other writers' essays on agency theory, which is the problem's likeliest port of entry into economics.[20] Only David Noble comes unambiguously to the conclusion: “Digital computers, high speed counters that can add and subtract discrete units of information fast enough to simulate complex logical processes, were a product of the war.”[21] Noble is almost certainly correct, and we may expect that independent scholars in coming years will bring this somewhat unpalatable truth to our attention, econometrically and otherwise.)

To be sure, the need for fast numerical calculation had been in the air for a century, as advances in engineering technique intensified the demand for complicated calculations. The prehistory of computers includes the analytical engine of Charles Babbage, a never-built assemblage of gears, cams, and racks the size of a small house; the widely used punch cards of Herman Hollerith; and the glorified adding machines of Howard Aiken, which could do three calculations a second. True, Alan Turing had published his intellectual blueprint for a computer in 1937, well before the war; but none of the men who actually built computers (John Atanasoff, Conrad Zuse, George Stibitz, Howard Aiken, J. Presper Eckert, or John Mauchley) read it. Statesmen and soldiers scarcely comprehended that fast calculations would prove useful in wartime; Germany drafted its leading computer architect.

Yet it was unmistakably in the cauldron of the war that the calculator gave way to the computer. Between Bletchley Park in England, where the problem was code cracking, and the Moore School at the University of Pennsylvania, where the problem was ballistic trajectories, a few dozen inventors, backed by large sums from the defense establishment (“large puddles of money,” in the words of one M.I.T. engineer), created the first electronic, digital, stored-program computers. John Von Neumann recognized the significance of ENIAC (Electronic Numerical Integrator and Computer—the first true computer) only after Herman Goldstine told him, while waiting for a train at the Aberdeen ballistics lab in Maryland, that he was going to visit a machine that could do three hundred calculations a minute. Within weeks, Von Neumann had succeeded in diverting ENIAC from the purpose for which it had been built—the calculation of firing tables for navy guns—to a more pressing project. When ENIAC was switched on in February 1946, its first task was making calculations on the feasibility of the hydrogen bomb.

It was the Cold War that put Massachusetts back in the computer business. Before the war, Vannevar Bush and a team at the Center for Analysis had been working on a very fast calculator, but with the advent of the war, the team dispersed to other projects. After the war, Warren Weaver and the Rockefeller Foundation pumped $100,000 into resuscitating the project, but by that time another candidate for funds had arisen within the university and from a fairly unexpected quarter. It simply muscled the Rockefeller Foundation and everyone else out of the way.

No single citizen of Massachusetts is responsible for more jobs in the state—or is more nearly anonymous—than Jay W. Forrester. Nebraska-born, Forrester came to M.I.T. in 1939. His wartime assignment in the Servomechanisms Laboratory was to build a universal airplane trainer, one that would simulate the operation of any airplane; after the usual number of twists and turns, he decided that what he needed was a digital computer rather than a machine full of axles and gears. He visited Von Neumann and the Moore School machines, concluded they'd never suit his purposes: they were too unreliable, not fast enough. And so while the rest of the infant computer industry labored away, planning to sell a dozen cartoon-style electronic brains a year, Forrester pounded away for the navy on a real time machine, capable of instantaneous calculation, in order to "put men in the loop."

Saved by the Bomb

For all his considerable success, Forrester's Whirlwind computer project probably would have been canceled had it not been for the Russian atom bomb that was exploded in August 1949. The idea of nuke-laden Russian planes flying over the North Pole—plus the outbreak of the Korean War—was enough to call into being the Semi-Automatic Ground Environment project, or SAGE, an "electronic radar fence" to be coordinated by computer. Forrester got the job, and he devised little iron doughnuts to replace vacuum tubes as the on-off basis for memory. With a fat air force contract to M.I.T. in his pocket, the company he picked to build these memories— in preference to Raytheon, Remington Rand, and Sylvania—was International Business Machines Corporation. The graduate student he sent to Poughkeepsie to supervise the process was a bright young man named Kenneth Olson.

So it was that in the early 1950s the U.S. government substantially bankrolled IBM's entry into the computer business. For the first few years after the war, the computer market had belonged mainly to Remington Rand, the firm that absorbed the company started by Moore School's Eckert and Mauchley. Raytheon and Engineering Research Associates (later to become Control Data Corporation in Minneapolis) were also active forces. Already a large and highly successful corporation, IBM was interested in electromechanical calculators (particularly those of Howard Aiken at Harvard), mainly as a way of selling more punch-card equipment to big accounts like Commonwealth Edison. A large faction within IBM, often led by Thomas Watson, Sr., was opposed to developing its electronics at all: "There were not unlimited funds within the IBM company," sniffed its director of engineering.[22] Yet the firm's younger executives saw the new wave coming. Thomas Watson, Jr., related years later that he had become "absolutely panicked" upon learning that two UNIVACs had been installed at the Census Bureau.[23]

The same Korean War that kept Jay Forrester in business at M.I.T. brought IBM's Tom Watson, Jr., to President Harry Truman to offer the services of the firm to the nation. The offer was pointedly not limited to existing systems, Watson said, and his company decided to go ahead and build a computer for the government and as many other takers as it could find—that was the Defense Calculator. But not until an IBM engineer named John McPherson went to a committee meeting in June 1952 to organize the Second Joint Computer Conference did he learn that Jay Forrester at M.I.T. was looking for a commercial manufacturer for his iron core memory. "One of the best payoffs that belonging to a professional society could produce," he said later. "I should have gotten a finder's fee."[24]

Suddenly, the government was precisely the huge honey pot for which Thomas Watson, Jr., had hoped two years earlier. To that point, computer building at IBM had been a tentative affair. But with SAGE, the company began by hiring thirty engineers—heavy-hitters like Gene Amdahl, Erich Bloch, Charles Bashe, Werner Bucholtz, Robert Crago, and Lawrence Kanter, among others—who were trained in the new electronic style and who promptly pushed out of the main engineering lab the old Edisonian tinkerers who had built the punch-card business. Under the SAGE contract, the company hired between seven and eight thousand engineering, programming, and maintenance workers, most of whom stayed on. During the 1950s, more than half of IBM's domestic electronic data processing revenues came from SAGE and from work on the B-52 bomber program in the Korean War.

IBM's big breakthrough—the Model T of the computer industry, Stan Augarten calls it—was its Model 650, announced in July 1953 and delivered in December 1954. Within a year, 120 machines had been installed and another 150 had been ordered, despite the product planning department's having declined to forecast a single sale. A series of improved models followed; yet as late as 1955, there were still company directors who wanted to get out of the business. But by then the company was ready to make the first of a series of dramatic gambles with its own money instead of government funding.

Nor was IBM the only one to roll the dice in those years. At about the same time, Kenneth Olson—the graduate student who had acquired a permanent disdain for IBM's strategic style while supervising the production of SAGE's memory—headed off to open his own memory company in an old abandoned mill in Maynard, Massachusetts. He called it Digital Equipment Corporation. Dozens of other young electrical engineers were going into business for themselves then, too. The rest, as they say, is history—rich, complicated, absorbing.

The $100 Billion Un-sure Thing

By this reckoning, virtually the entire modern computer business can be said to have been a fairly direct outgrowth of those few years, say, from 1940 to 1955. In 1985, that amounted to around 265,000 jobs, or about 9 percent of the 3 million jobs in Massachusetts. Traditional manufacturing jobs accounted for 675,000 of the total. So does it matter, thirty years later, that IBM in 1953 "ate Raytheon's lunch," as the businessmen say? Does it matter that the first computer factory went to Poughkeepsie? The fact remains that, thanks mainly to the Servomechanisms Laboratory at M.I.T., Massachusetts was able to make a firm entry into the fledgling electronic computer industry in the 1950s. The Commonwealth's history in semiconductors, however, hasn't been nearly as triumphant. Even though Lincoln Laboratories pioneered in investigating the electrical properties of silicon, interest in the technology flagged after World War II, and when William Shockley, who had invented the transistor at Bell Laboratories, returned to Stanford University to pursue his research, the result was that the area around San Francisco became dominant in the new technology—the Boston area fell far behind.

Nor was it simply new business in Massachusetts that benefited from the wartime spending boom. General Electric had arrived in Massachusetts in the 1890s, when Thomas Edison's firm bought one of its strong competitors, Lynn's Thompson Houston Electric Company. The smaller company's management promptly took over the larger firm, and GE acquired a strong connection with M.I.T. (It was Gerard Swope, for example, who in 1930 recruited Karl Compton to preside as president over the modern transformation of the school.) Raytheon Corporation had been a by-product of GE's struggle with Bell over who would control the market for commercial radio. Both firms grew large and diverse on military contracts during World War II. The manufacture of airplane engines, which had flourished along the Connecticut and Housatonic rivers since World War I because of the presence there of the nation's most sophisticated metal-cutting trade, boomed accordingly: when General Electric decided to enter the market in 1941, the government built a plant for it in Everett. Some firms gorged on military spending, grew fat, and eventually failed: Curtis Wright is a prime example. But around a solid industrial core, dozens of little companies took root and grew: a rocket-fuel plant learned to make bleach for newspaper pulp instead; a company that invented shock-proof mounts for shipboard radars turned to pylons for jet engines; and so on.

Looking backward, 1942 seems to be the year in which the rules of the game changed decisively. That was when the Radiation Lab was established at M.I.T. to pursue the development of the British invention of radar. Again, the details are illuminating: Boston got the job, in preference to Bolling Field in Washington, after M.I.T.'s James Killian arranged hangar and lab space in a few hours. The Radiation Lab undertook three jobs—to build a flying radar, a gun-laying system, and a long-range navigation system that became LORAN—and to this end assembled a large collection of theoretical physicists. It was no foregone conclusion that this would work: M.I.T. had to overcome objections of the man who put Bell Labs together, Frank Jewett, who couldn't believe that a group of young scientists working in an academic environment could do the job. By the end of the war, 20 percent of the nation's top physicists had passed through the lab and had compiled an unprecedented record of scientific and technological success.

It is worth inquiring a little further into the nature of this watershed. Frank Jewett's objection to the establishment of the Radiation Lab was not unique. Before World War II, America had relatively little experience with large-scale organization for research. But whether in the Manhattan Project, the Radiation Lab, the Office of Strategic Services, the "whiz kids" in the army air force, the group around William Norris at the Office of Naval Intelligence, or a hundred other groups of slightly lesser magnitude, the successes were so immediate and so far-reaching that they changed forever the way business is done: this was nothing less than the very invention of "high tech." The nub of the process has been identified by Gerald Holton in *Thematic*

Origins of Scientific Thought:

> What took place was analogous to impedance matching, the method by which an electronics engineer mediates between the different components of a larger system. That is, special coupling elements are introduced between any two separately designed components, and these allow current impulses or other message units to pass smoothly from one to the other. Similarly, in these quickly assembled groups of physicists, chemists, mathematicians, and engineers, it was found that the individual members could learn enough of some one field to provide impedance matching to one or a few other members of the group.[25]

I want to emphasize that this threshold phenomenon is at the heart of the success of all the large units with which we are concerned here: universities, cities, and nations, as well as research teams.

Situation Normal, All Fouled Up

Not that the transfer of military technology to civilian markets has ever been easy. The commercial success of the computer has been one of the big surprises of the postwar era, even to its enthusiasts, and not the least surprising part was the applicability of computers to relatively intimate situations. That the extent of this potential was not apparent, even to the smart guys who pioneered in the development of the machine, is fascinating. Aiken had pooh-poohed it; Eckert had doubted; even the great Von Neumann had thought of computers mainly as calculators, and had failed to foresee their ultimate utility as storehouses of information. Even IBM failed to appreciate how flexible the machines could be made; that was "the M.I.T. idea," as Kenneth Olson of Digital Equipment has described it, and the role played by the Massachusetts firms—DEC, Wang, Data General—in forcing IBM's hand is still underappreciated. True, the record of the computer industry is littered with sad stories of companies, Raytheon and General Electric among them, that tried to get into the industry and failed. But in 1982, there were a half million general-purpose computers in use, and the number was growing by 40 percent a year.

Nor is it that the military never makes mistakes—least of all that. The navy tried hard to pull the plug on Jay Forrester's Whirlwind computer, for example. The National Bureau of Standards, working in deepest secrecy for the navy, began Project Tinkertoy in 1950 to create components that could be put together hierarchically with ease. More than $5 million later, it turned out that Tinkertoy was based on vacuum tubes instead of newly invented transistors. Similarly, the Signal Corps spent $25 million on RCA's attempt to create the same kind of modules, this time with transistors, just as the integrated circuit was coming into use. On the other hand, the government often bets right. In the 1960s and early 1970s, the Defense Advanced Projects Research Agency funded much of the early work on time sharing and networking, two of the standard techniques for getting computers to work together. The military research is like the old saw about advertising: half of it is wasted—if only we knew which half.

Close to the truth is what Leo Steg says about the effect of military targeting. For twenty-three years Steg was head of General Electric's Science Laboratory; he says the trick is for the government to announce a standard, to set a target for which everyone can shoot.[26] Then smart guys, like the Texas Instruments crew in the case of semiconductors, can either hang along on the outside of the camp or join the governmental effort, and it doesn't really matter who hits the jackpot. Integrated circuit coinventor Jack Kilby of Texas Instruments worked on RCA's Micromodule despite his loathing of the technology involved. Something of the same sort was at work when M.I.T.'s John C. Sheehan succeeded in synthesizing penicillin where a huge wartime effort had failed. In addition to this "outsider" mechanism, there is the effect of all that money: the government can afford to back a lot of losers in order to find one winner.

It was in this way that semiconductors made their way into the commercial marketplace, via the Apollo space program and a hundred less conspicuous military uses. The first integrated circuits were offered for sale in 1961, but government sales constituted 100 percent of the market until 1964, and the federal government remained the largest buyer of chips for years after that, according to T. R. Reid. But just as had been the case with computers, as manufacturers made more and more chips, their manufacturing costs fell. By 1969, when IBM bowed to the inevitable and began using chips in all logic circuitry, chip makers finally "had a market that would dwarf the space and defense business," Reid says.[27] By the late 1970s, when the attention of the semiconductor firms had drifted away from defense, the Defense Department concocted a program that brought their representatives back to the program: the Very High Speed Integrated Circuit project.

It is in this light that the headlines about military spending should be read, with skepticism for strong stands on either side of the issue. Unexpected ties between government spending and civilian industry are everywhere.

Local Politics, National Agendas

What place is there for politics in this story? Well, certainly there is a very large one, and it deserves to be told in detail elsewhere. No one understands the political realm better than my colleague Martin Nolan, who spent fifteen years in Washington, D.C., before taking over the editorial page of the *Boston Globe.* When I asked him about the role the congressional delegation had played in shaping the composition of the defense industry in Massachusetts, he said that the politicians had won some and lost some.

> For instance, the NASA mission control center should, by all rights, be in Cambridge, Massachusetts. But Albert Thomas of—guess where?—Houston, Texas, happened to be head of the Independent Agencies Subcommittee of the House Appropriations Committee at the time, and even with their guy in the White House, Massachusetts wasn't able to get it. The Texans stole it fair and square. The Massachusetts delegation was pretty good over the years, but there was nobody better than the Texans at getting on the important committees. One of their guys was on the Armed Services Committee because his district had a lot of goats and he figured you could sell goat skins to the military easier than to anyone else. The influence of the Massachusetts delegation began to fade in the 1960s; Leverett Saltonstall didn't stand for reelection in 1966; Bill Bates died and was replaced by Michael Harrington in 1970; Phil Philbin was defeated by Father Drinan on a strong antiwar program in the primary the very year before he would have taken over the Armed Services Committee. The Vietnam War slowed down; so did the moon program. Then Richard Nixon sent Elliot Richardson—Elliot Richardson, of all people—to shut the bases. There was gloom and doom all around.[28]

That was, of course, the dark before the dawn. The biggest boom since the end of the nineteenth century was about to energize the Massachusetts economy. What happened? Well, in the view presented here, the main motors of the boom were the commercial phases of the high-tech and minicomputer revolutions, engines that had started turning some thirty years earlier. That interpretation is all right with Nolan—as far as it goes. He cites the thesis of Don K. Price, who in his book *The Scientific Estate* credits Rep. Thomas P. O'Neill with being "the hero of a turning point in [scientific] history."[29] When O'Neill, in January 1963, declined a very favorable proposition from NASA to hire engineers for Washington jobs on a strictly nonpartisan basis, Price wrote, he was acting on the basis of a deep understanding of the relationship between political and economic power: "If he turned down Washington jobs on behalf of his constituents, it was because he was interested in a far more substantial form of patronage: contracts in Boston for industrial corporations and universities."[30] The balance had decisively shifted away from standing armies to technological weapons and the experts who built them—wizards, in Churchill's phrase, or boffins, in the British slang of the war—and increasingly, the politicians realized it. The definitive version of the political history of these remarkable last forty years awaits Nolan's own accounting of the period, but until then, Price's book makes the best reading.

Boffins Regnant

The intricately connected social world in which all this activity took place is the vital counterpart to the abstraction of the cost web that we met earlier. Politics are just part of it, and in the short run, not the most important part. At least as important as the legislative leadership has been the administrative apparatus of science and technology—the boffinate, if you will. M.I.T.'s Vannevar Bush was science adviser to President Roosevelt. M.I.T.'s James Killian and Harvard's George Kistiakowsky were advisers to President Eisenhower, M.I.T.'s Jerome Wiesner adviser to President Kennedy, Princeton's Don Hornig (a Harvard College graduate and Harvard Ph.D.) to President Johnson. Lee DuBridge, who had directed M.I.T.'s Radiation Lab during the war, was adviser to President Nixon; so was Exxon's Edward David, Jr., whose doctorate came from M.I.T. H. Guyford Stever, who had spent twenty-five years at M.I.T., served Presidents Nixon and Ford; M.I.T.'s Frank Press was adviser to President Carter. Ronald Reagan's science adviser, George Keyworth II, was the first man to hold the job who never went to school or taught in Boston—and he was born in Boston.

These high-ranking bureaucrats, who commanded the pinnacle of what was an extensive administrative machinery of science, were in a position to send important business to New England, and often did. Nor did the appeal of the universities to business operate only through their influence on the federal machinery. Harvard University, too, has been highly successful in furnishing advisers to government, but there is an important flip side to M.I.T.'s efforts: since the school is far less rich than Harvard, it has had to forge intricate connections to industry as well as to government in search of funds. The modern phase of this outreach began in 1948, with its industrial liaison program. The result is that M.I.T. has a degree of clout with the corporate community that far exceeds that of Harvard.

If the dense educational and research establishment is the single dominant feature of the business infrastructure in Boston, it is hardly the only element that matters. Important also is the city's venture capital community, its banks and investment managers: the availability of cash to bring along fledgling enterprises has been another linchpin in Boston's development since it lured Alexander Graham Bell more than one hundred years ago. Also important is the willingness of the Commonwealth to let inventors keep their wealth, if and when they earn it. Walter Muther, president of the Associated Industries of Massachusetts and dean of the State House lobbyists, contends that the legislative supervision of inheritance and capital gains is the unheralded key to the state's success in attracting and keeping start-up companies.[31]

It may be that low taxes attract businesses and high taxes drive them out. Still, the map of states, viewed through this lens of defense spending, will turn up cities—like hot spots of infrared emissions—whose postwar growth has been built in large part around their universities: Cal Tech/UCLA, Berkeley/Stanford, M.I.T./Harvard, Columbia/New York University, the University of Texas at Austin, the University of Chicago/Northwestern University, the cluster of universities around Washington, D.C., and so forth. Only geographic distinction confers greater advantage when it comes to competing for Pentagon dollars. Indeed, it is possible to make some comparisons of size and shape here. In table 1, which is based on a recent study by Data Resources, Inc., Massachusetts is seen to be among the top ten states in defense spending as a share of total state product, the local contribution to GNP. At 6.6 percent, it is behind Virginia (10.4 percent); Connecticut (9.7 percent); Hawaii (8.7 percent); Washington (7.9 percent); California (7.9 percent); Maryland (7.3 percent); and Alaska (7.3 percent); and ahead of Missouri (6.5 percent); Mississippi (6.4 percent); and New Hampshire (6.4 percent). Moreover, DRI calculates that Massachusetts will share disproportionately in the growth of military spending through the rest of the decade, along with a handful of other states. Connecticut, Massachusetts, Maryland, Vermont, Virginia, and Washington are all expected to obtain 15 percent or more of their growth from military spending during the next five years.

What Next?

We are currently caught up in a remarkable new evolution, one as laden with potential economic benefits as with terror. I mean, of course, Star Wars, as the president's Strategic Defense Initiative has become known. In fact, it has less to do with nail guns and x-ray lasers than with software. The opposition to Star Wars is bucking a huge wave that is breaking over the engineering and electronic business, having to do with the conquest of new frontiers, namely, the design and manipulation of very complex systems—the issues that crop up when engineers try to design chips with a million and more gates or to write computer programs with hundreds of thousands of lines.

What about Star Wars as a weapon? Certainly I am deeply skeptical, but my skepticism is grounded in little more than a newspaperman's common sense. A low level of research and development is one thing. But is it possible to fund the research and keep the weapons at home? Perhaps. Certainly to do so will require a considerable amount of fairly stiff-backed opposition on the part of a wide segment of the research community. One needs to keep firmly in mind the idea that technologies are systems with enormous momentum, and that opposition on a local level, along only one part of their advancing salient, is doomed to fail. Yet, as Thomas Hughes says, external forces can redirect even high-momentum systems.

It can be said with confidence, I think, that once again some huge payoffs await breakthroughs made along the lines taken by government funding. Whether they

Table 1

Defense and Non-Defense Output by State, 1985

State	Production (billions of dollars) Defense	All Other	Defense Share of Total (percent)
Alabama	4.3	96.0	4.3
Alaska	1.1	13.4	7.3
Arizona	4.1	73.8	5.3
Arkansas	2.0	58.8	3.4
California	63.1	732.0	7.9
Colorado	4.8	106.8	4.3
Connecticut	9.8	91.4	9.7
Delaware	0.5	19.2	2.5
Dist. of Colum.	2.0	41.8	4.6
Florida	13.8	283.7	4.6
Georgia	7.3	165.8	4.2
Hawaii	2.3	24.4	8.7
Idaho	0.6	23.1	2.4
Illinois	9.7	349.3	2.7
Indiana	7.2	161.7	4.3
Iowa	1.7	85.9	2.0
Kansas	3.8	78.6	4.6
Kentucky	3.0	91.5	3.1
Louisiana	5.3	140.9	3.6
Maine	1.5	26.4	5.3
Maryland	8.6	108.1	7.3
Massachusetts	12.0	167.9	6.6
Michigan	7.2	275.0	2.6
Minnesota	4.5	126.4	3.5
Mississippi	3.7	54.3	6.4
Missouri	9.4	135.7	6.5
Montana	0.5	19.7	2.5
Nebraska	1.2	48.5	2.4
Nevada	0.7	25.4	2.6
New Hampshire	1.8	25.5	6.4
New Jersey	8.7	220.8	3.8
New Mexico	1.7	31.7	5.0
New York	21.7	478.8	4.3
North Carolina	5.6	178.5	3.0
North Dakota	0.5	16.8	2.7
Ohio	11.8	307.8	3.7
Oklahoma	3.4	85.6	3.8
Oregon	1.6	63.6	2.5
Pennsylvania	13.3	322.0	4.0
Rhode Island	1.3	26.7	4.7
South Carolina	3.6	83.0	4.2
South Dakota	0.4	19.0	2.0
Tennessee	3.8	127.0	2.9
Texas	24.6	532.6	4.4
Utah	2.3	41.8	5.3
Vermont	0.6	12.6	4.3
Virginia	16.5	142.4	10.4
Washington	8.9	103.5	7.9
West Virginia	1.3	42.5	2.9
Wisconsin	3.5	145.0	2.4
Wyoming	0.5	17.5	2.7

Source: George F. Brown, Jr., "Regional Prospects for Defense Supplying Industries," Data Resources, Inc., 30 April 1985 come inside the research effort or outside it is, as always, open to doubt. It is this ambiguity that has rendered the Europeans relatively enthusiastic backers of the SDI—the Star Wars program is "a mini-Marshall Plan" that will get England growing again, says Sir Peter Emery, a British MP and businessman[32]—while the Japanese remain relatively skeptical; despite more than a year of formal study at the cabinet level, the Japanese government has yet to declare its support. What seems likely to emerge from the next twenty years of research is not so much new ways of manufacturing computers as new ways of controlling and linking them. These techniques may offer a unique competitive advantage to the companies that possess them. After all, America has seen its domestic television-manufacturing industry move offshore without noticeably bad results. Does it matter who makes the cathode-ray tubes if the real money is in the television networks? It may be the same with software and the design and manufacture of the most advanced computers.

Considerations like these make it devilishly hard to think about defense economics. But to ignore them is to willfully misunderstand the questions. In the past century, military spending has often been a powerful accelerant to economic growth. That is one reason—perhaps the main reason—it is so very difficult to curb.

Notes

1. The best single account of Boston's military beginnings is the abridged edition of Gary B. Nash, *The Urban Crucible* (Cambridge, Mass.: Harvard University Press, 1986).
2. See Alain Cass and Simon Henderson, "The Nuclear Threat Behind Pakistan's Grim Pursuit," *Financial Times* (13 June 1985): 3.
3. M. R. Montgomery, personal conversation with the author, 23 January 1986.
4. *Public Papers of the Presidents of the United States: Dwight D. Eisenhower, 1960–61* (Washington, D.C.: Office of the Federal Register of the National Archives Records Service).
5. Jacques S. Gansler, *The Defense Industry* (Cambridge, Mass.: MIT Press, 1980).
6. James Fallows, *National Defense* (New York: Random House, 1981).
7. Merritt Roe Smith, ed., *Military Enterprise and Technological Change* (Cambridge, Mass.: MIT Press, 1985).
8. Cost webs are discussed in David Warsh, *The Idea of Economic Complexity* (New York: Penguin Books, 1985).
9. "Reagan: I'll Sell Agencies," *Boston Sunday Herald,* 9 February 1986, 10.
10. For well-informed accounts of the worlds of SIOPS theorists, see Fred Kaplan, *The Wizards of Armageddon* (New York: Simon & Schuster, 1983), and Gregg Herken, *Counsels of War* (New York: Alfred A. Knopf, 1985).
11. Mark McCain, "Business Group Takes on the Defense Establishment," *Boston Sunday Globe*, 23 June 1985, 10.
12. Emma Rothschild, "Boom and Bust," *New York Review of Books,* 3 April 1980.
13. Seymour Melman, *Profits Without Production* (New York: Alfred A. Knopf, 1983).
14. Lester Thurow, "How to Wreck the Economy," *New York Review of Books,* 14 May 1981.
15. Melman, *Profits Without Production,* xv.
16. Carroll W. Pursell, Jr., "The Problematic Nature of Late American Technology," in *The History of American Technology: Exhilaration or Discontent?* ed. David Hounshell (Wilmington, Del.: Hagley Museum and Library, 1984).

17. Brooke Hindle, "The Exhilaration of Early American Technology: A New Look," in *The History of American Technology: Exhilaration or Discontent?*

18. The criticism of present-day arrangements by the design-of-work people seems to me to be highly useful. The utopian task of imagining how life could be different is an important function; we should—and do—welcome criticism of present styles of the organization of work. One has only to think of the changing role of women to see how misleading at any particular time the conventional wisdom can be which states that the present way is the only natural way.

19. I am indebted to Merritt Roe Smith's essay in *Military Enterprise and Technological Change* for these quotations.

20. This article's stylized account of the origins of the digital electronic computer is drawn from Stan Augarten, *Bit by Bit* (New York: Ticknor & Fields, 1984); Joel Shurkin, *Engines of the Mind* (New York: Norton, 1983); T. R. Reid, *The Chip* (New York: Simon & Schuster, 1984); David Ritchie, *The Computer Pioneers* (New York: Simon & Schuster, 1985); Karl L. Wildes and Nilo A. Lindgren, *A Century of Electrical Engineering and Computer Science at MIT, 1882–1982* (Cambridge, Mass.: MIT Press, 1985); James R. Killian, Jr., *The Education of a College President* (Cambridge, Mass.: MIT Press, 1985); Franklin M. Fisher, James W. McKie, and Richard B. Mancke, *IBM and the U.S. Data Processing Industry: An Economic History* (New York: Praeger, 1983); Emerson Pugh, *Memories That Shaped an Industry* (Cambridge, Mass.: MIT Press, 1984); and Leonard S. Reich, *The Making of American Industrial Research* (Cambridge: Cambridge University Press, 1985). John W. Pratt and Richard J. Zeckhauser introduce agency theory in *Principals and Agents: The Structure of Business* (Boston: Harvard Business School Press, 1985).

21. David Noble, *The Forces of Production* (New York: Alfred A. Knopf, 1984), 49.

22. Fisher, McKie, and Mancke, *IBM and the U.S. Data Processing Industry,* 12.

23. Ritchie, *The Computer Pioneer,* 243.

24. Pugh, *Memories That Shaped an Industry,* 93.

25. Gerald Holton, *Thematic Origins of Scientific Thought* (Harvard University Press, 1973), 410.

26. David Warsh, "Star Wars: Boon or Bane for Economy?" *Boston Globe,* 21 November 1985, 57.

27. Reid, *The Chip,* 126.

28. Martin F. Nolan, personal conversation with the author, 7 February 1986.

29. Don K. Price, *The Scientific Estate* (Cambridge, Mass.: Harvard University Press, 1965).

30. Ibid., 21.

31. Walter Muther, personal conversation with the author, 26 January 1984.

32. Flora Lewis, "Foreign Affairs," "Upside Down Values," *New York Times,* 9 February 1986, sec. 4, 23.