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A SURVEY OF DUAL-USE ISSUES

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INSTITUTE FOR DEFENSE ANALYSES

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PREFACE

Since October 1992 the Institute for Defense Analyses (IDA) has assisted the Defense Advanced Research Projects Agency (DARPA) with economic advice and technology policy recommendations regarding the Technology Reinvestment Project (TRP) under the task entitled "The Economic Impacts of Technology Investments." The purpose of the TRP is to promote integration of the commercial and military industrial bases to improve the affordability of weapons and systems while also contributing to the commercial competitiveness of U.S. industry through dual-use technology investments.

In September of 1995, DARPA asked IDA to conduct a survey of issues raised in the dual-use literature in support of a broader effort to address the future of dual-use technology programs. In particular, DARPA requested that this survey be used to support, and be incorporated into, the deliberations of an expert panel funded through a grant to the Potomac Institute for Policy Studies (PIPS). An early draft of the paper was provided to the sponsor for use by the panel, and the present fully reviewed and edited version was subsequently produced.

The authors would like to extend their warmest appreciation to the reviewers of this paper for their significant effort to improve both its content and organization. Special thanks go to Jay Stowsky of the University of California and to David Graham and Andrew Hull of the Institute for Defense Analyses. Thanks are also due to Cori Bradford for preparing the manuscript, and to Shelley Smith for fine editorial assistance.

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The nature of nomadic society on the steppe was such that to speak of the Mongol army is really no more than to speak of the Mongol people in one of its natural aspects. For the whole of life was a process of military training. The same techniques that were necessary for survival in a herding and hunting environment were, with very little adaptation, those used in warfare.

This was particularly true of hunting. The Mongols mounted an annual expedition for the acquisition of meat to tide them through the hard Mongolian winter. This took the form of a nerge, a vast ring of hunters, which gradually contracted, driving the game before it. Any hunter who allowed an animal to escape from the ring, or who killed one before the appointed time, was punished. At the end the khan would loose the first arrow, and the slaughter would commence. A few emaciated stragglers would ultimately be spared. Juwayni remarks that "war - with its killing, counting of the slain and sparing of the survivors - is after the same fashion, and indeed analogous in every detail."

—David Morgan (1986), *The Mongols*

I. INTRODUCTION

In general, we believe most of the technologies the Defense Department depends upon—electronics, semiconductors and computer software, to mention a few—have equivalents in the commercial industry. Therefore we do not believe we have to maintain a defense-unique capability in those areas.

—Dr. William Perry, Secretary of Defense

Events since the demolition of the Berlin Wall in 1989 have dramatically changed the face of international security. But while the Cold War may be over, recent developments in the Middle and Far East, Africa, Europe, and the Caribbean suggest that military security will remain an important concern for the foreseeable future. To deal with anticipated regional contingencies, U.S. forces need not be as vast as they were during the past 45 years; however, they will continue to face formidable challenges. Our choices are either to equip the military from a shrinking, dedicated defense industrial base and face certain degradation in quality and capabilities, or to adapt military requirements and procurement strategies so that they rely upon commercial industrial capabilities.

The second approach, increased reliance on commercial industry, seeks to improve the capabilities and affordability of weapon systems by promoting greater commonality between commercial and defense items (so-called dual-use). This objective would be accomplished along a variety of fronts—in manufacturing, for instance, by co-producing commercial and military items in the same facilities and, where practical, on the same production lines; in research and development, by developing and nurturing technologies with a potential to be both commercially viable in the competitive marketplace and militarily applicable.

A. ISSUES ADDRESSED

This paper is a survey of various issues regarding the efficacy and applicability of dual-use concepts to promote greater national security, both military and economic. It responds to five questions posed to the study team regarding the history, recent experience, and possible future of dual-use strategies to support and further the missions of the Department of Defense:

1. What are the potential benefits from dual-use for the military?
2. What are the motivation and rationales for commercial industry to pursue dual-use technologies?
3. What are the possible processes for choosing technology investment focus areas for dual-use projects, and are there associated advantages and disadvantages for each approach?
4. What are optimal strategies for integrating the four military services (Army, Navy, Air Force, Marines) into a single dual-use program under the Office of the Secretary of Defense (OSD)?
5. What are optimal strategies for conducting an OSD level dual-use program?

For the purposes of this paper we chose to view these as falling into two categories. Questions 1 and 2 clearly relate to the underlying bases for pursuing dual-use, including history, institutional motivations, and technical and political considerations; Questions 3, 4, and 5 are programmatic in nature.

B. PLAN OF THE PAPER

In the past decade, much has been written about dual-use, particularly regarding the important benefits to the commercial world from spin-off, or the migration of military technologies and capabilities into commercial use. More recently a literature has also amassed regarding the benefits from spin-on, or the government's use of commercial technologies to bolster and make military capabilities more affordable. Both of these subjects are covered in a number of excellent sources: books such as *Beyond Spin-off* and *The Relation between Defence and Civil Technologies*; reports by the Office of Technology Assessment and the Center for Strategic and International Studies; studies by deliberative bodies such as the Defense Conversion Commission, the Carnegie Commission on Science, Technology, and Government, and the Packard Commission; and a host of government documents associated with dual-use efforts by the Department of Defense (Appendix E contains a bibliography of dual-use sources of information).

Based on these and other sources, as well as new independent research, this paper addresses the questions posed to the study team in two ways. First, it offers a commentary on the observations and conclusions of these various literatures. Second, it provides additional analysis in areas deemed relevant to the particular questions at hand. The paper proceeds as follows.

Chapter 2 presents a framework for understanding the different meanings of the term "dual-use" by briefly reviewing the contexts in which it is used by different constituencies. It then examines how one would operationalize the concept, particularly as dual-use may be used to meet DoD requirements. The chapter also provides the foundation for succeeding discussions of the historical circumstances that have given rise to dual-use, both successes and failures.

Chapter 3 is an abridged overview of U.S. technology and dual-use policies since the end of the Second World War. It presents a short historical retrospective on technology policy, reviews dual-use policies in DoD prior to the Technology Reinvestment Project (TRP), and observes the explicit linkage between military and economic industrial base issues promoted by the Clinton administration. The chapter provides the framework for discussions in Chapter 4 which addresses the interwar period (1920 to 1936) dual-use activities that are corollary to post-Cold War experiences and the growing use of research and development consortia within the past 15 years.

Chapters 5 and 6 are structured much like Chapters 3 and 4. Chapter 5 reviews technology policies (strategies) employed by other nations, while Chapter 6 offers historical dual-use examples from Japan, China, the United Kingdom, and Brazil.

Chapter 7 applies the lessons learned in the preceding chapters to the issue of constructing federal government dual-use programs. It addresses, in turn, dual-use and industrial base integration, public sector choice of technology investments, legal and institutional issues, and principles for organizing a DoD dual-use program. Chapter 8 concludes the paper by offering our findings regarding the main themes of the dual-use literature reviewed and specifically responds to the study questions posed.

Each chapter concludes with a summary of our findings in a particular area and an explicit statement of their implications for dual-use programs. Chapter 8 provides a synthesis of all our findings and clearly answers the five questions that drove our research.

II. DUAL-USE AND NATIONAL SECURITY

The term "dual-use" conveys many different meanings and is endowed with passionate overtones by constituencies with competing institutional and political objectives. This chapter first explores the bases for these varied definitions. Rather than attempting to establish a unique meaning for the term, we suggest some perspectives for assessing the different contexts in which it is used and offer four models that present alternative approaches for advancing the concept. We then discuss the operationalization of dual-use as it applies to commercial and military needs. We conclude this chapter by addressing issues surrounding the relevance of dual-use for meeting defense requirements and carrying out military missions.

A. WHAT IS DUAL-USE?

"Dual-use" is a well-worn term of art. Even so, a literature review uncovers considerable unevenness in its employment and interpretation. There are many definitions of dual-use, with constituencies applying the concept differently to support their positions. Some of these definitions are very simple and general, such as that found in *Beyond Spinoff*: [T]he term 'dual-use technology' refers to technology that has both military and commercial applications, and the relationship between the military and commercial sectors is called the 'dual-use relationship.'"[1] A more comprehensive definition of dual-use is encountered in *Adjusting to the Drawdown: Report of the Defense Conversion Commission*, where dual-use is interpreted according to whether it is used in reference to products, processes, or technologies.

> **Definition of Dual-Use Technology:** "Dual-use technology refers to fields of research and development that have potential application to both defense and commercial production. Some technologies are important for both DoD and commercial customers. Imaging-sensor technology, for example, has broad applications in surveillance systems, video cameras, and robot vision systems that find both military and commercial uses. In fact, at the generic level, most of today's important technologies can be considered dual-use."

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1 Alic et al. 1992, 4.

Definition of Dual-Use Processes: "Dual-use processes are those that can be used in the manufacture of both defense and commercial products, such as soldering, process control, and computer-aided design. For defense acquisition, these processes are frequently tied to military standards that may make them defense-unique, resulting in the segregation of defense and commercial production."

Definition of Dual-Use Products: "Dual-use products are items used by both military and commercial customers. Notable examples are global positioning systems used for navigation, aircraft engines, and most medical and safety equipment used by DoD. Some modified commercial products are similar enough to those used by the military to be considered dual-use. Some examples are the Air Force's KC-10A Extender aircraft (which is a modified version of the McDonnell-Douglas DC-10 commercial aircraft) and the Army's light cargo vehicle, the CUCV (which is a modified version of the Chevy Blazer). DoD's ability to buy dual-use products is limited by the requirements of military specifications and standards and by the degree to which commercial firms are willing to comply with defense purchasing requirements."[2]

Another variant of dual-use is found in *The Economics of Commercial-Military Integration and Dual-Use Technology Investments*, which says that a product or process that has both commercial and military applications "might be dual-use and employed militarily but not commercially because of cost, performance, regulations, or other considerations."[3] There is even a legally mandated definition of dual-use: "Dual-use,

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2 U.S. Department of Defense 1992, 30-31.

3 White and Tai 1995, 7.

"It is important to clearly distinguish between dual-use and CMI [commercial-military integration]. When we speak of "dual-use," we are referring to a product or process that has both military and commercial applications. In the case of dual-use technologies, this extends to knowledge3 that is applicable in both sectors. The concept of dual-use therefore relates to the characteristics of a product, process, or know-how without regard to the desirability of its application in either sector. Hence, an item might be dual-use and employed militarily but not commercially because of cost, performance, regulations, or other considerations.

CMI, on the other hand, is a process that seeks to exploit the "dual-usefulness" of products or processes to arrive at more efficient and cost effective solutions jointly for the commercial and military sectors. *Commercial-military integration is achieved when the production of commercially viable and militarily useful products is conducted jointly using common production inputs, and outputs are sold at prices comparable to those set by commercial markets.* Note that this definition involves two dimensions, an engineering one ensuring the commonalty of resources and production techniques, and an economic one ensuring the comparability of costs and prices. The former represents the traditional Cold War military considerations regarding performance; the latter, the post-Cold War affordability concerns that underlie CMI as pursued through current DoD policies."

with respect to products, services, standards, processes, or acquisition practices, means products, services, standards, processes, or acquisition practices, respectively, that are capable of meeting requirements for military and nonmilitary application."[4]

Beyond academic attempts to establish a proximate definition for dual-use, context begins to rule content. In particular, because "technology" has become a pervasive, perhaps ubiquitous, theme in modern society, and because the federal government plays a large role in funding scientific and technological endeavor in the United States, dual-use has become an issue in debates far afield of the commercial-military context in which it first emerged.

The Clinton administration, for instance, entered office on a platform that included the use of technology investments to leverage higher rates of economic growth.[5] Of their two flagship programs, the Advanced Technology Program (ATP) and the Technology Reinvestment Project (TRP), the latter was originally sold as a means of meeting commercial and military needs concurrently.[6] In particular, the TRP distinguished between three approaches to increasing the pervasiveness of dual-use through technology investments: *spin-off* to transition or transfer military capabilities for commercial use; *spin-on* to apply commercial capabilities to fulfill military missions; and *dual-use* to pursue the development of capabilities that simultaneously meet both commercial and military needs "from whole cloth." While all three approaches were advanced by the TRP, initially the program was promoted by the administration as part of its defense conversion activities—spin-off was seen as a way to assist ailing defense contractors to find commercial markets and ameliorate employment impacts from defense downsizing. Even with strong administration backing, however, forces reshaping the political landscape eventually led the program to move away from this emphasis to focus more directly on meeting the needs of the military through spin-on.

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4 Taken from 10 U.S.C. § 2491.

5 See, for instance: Executive Office of the President 1993a and 1993b.

6 The mission statement contains a clear expression of the economic dimension of the TRP:

"**TECHNOLOGY REINVESTMENT PROJECT MISSION:** To stimulate the transition to a growing, integrated, national industrial capability which provides the most advanced, affordable, military systems and the most competitive commercial products.

TECHNOLOGY REINVESTMENT PROJECT STRATEGY: Invest Title IV funds in activities which:

1) Develop technologies which enable new products and processes.
2) Deploy existing technology into commercial and military products and processes.
3) Stimulate the integration of military and commercial research and production activities."

Source: Department of Defense 10 March 1993, 2-1.

This change evolved when the Democratic majority in Congress was replaced by a Republican one which embraced an inverse position on the role of government in economic affairs. Whereas when in the majority the Democrats generally regarded dual-use defense spending as economically important and approved of the pursuit of spin-off defense technology for commercial use,[7] Republicans see such use of defense monies as "pork" which detracts from the ability of the Department to carry out its military missions.[8] (This debate also extends to the much larger issue of the appropriate role for government in "picking winners and losers," an issue that we address below.) As a result, administration officials shifted emphasis from the spin-off and defense conversion theme for TRP investments to a spin-on theme. That is, dual-use was pursued not through the application of DoD-funded developments in commercial pursuits, but through the application of commercial developments to satisfy military needs.

While the TRP must certainly be regarded as the most concerted effort to promote dual-use as part of overall DoD policies in the past 50 years, historically the Armed Services have always shown a willingness to engage in spin-on activities where they fit ongoing military programs and needs. In particular, the Service operational communities, usually termed "users" or "warfighters," have always been very interested in commercial-off-the-shelf (COTS) items and non-developmental items (NDIs) that have desired functionality and can be delivered far ahead of similar items developed within the acquisition system. Recent examples of this may be found in the area of telecommunications and computing: the Navy relies on TAC-3 and TAC-4 computers which are effectively COTS Hewlett Packard equipment; the Army and Air Force source from Sun Microsystems; the Defense Information Systems Agency (DISA) is redesigning global command and control using COTS computers and software, where possible, in the Global Command and Control System (GCCS); and, logistics is increasingly being

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7 See Appendix C, where we quote at length Section 2501 of the 1993 Defense Authorization Act, which contains significant references to the economic impacts sought from defense reinvestment and transition assistance monies used for dual-use technologies and defense conversion. There is also considerable discussion of the use of DoD monies to further the economic goals of defense conversion to be found in the Congressional Record of the 103rd Congress.

8 Senator McCain epitomizes the strongest of the Republican stands on the use of Defense monies, stating that in the FY 1994 DoD appropriations bill "the House set aside $6.5 billion of defense dollars for special interest, noncompetitive projects at bases, universities, and other institutions of the Members' home districts. In other words, the House gave its Members $6.5 billion in pork barrel projects. . . . The dollars earmarked for these and other programs like them are dollars taken away from identified, higher priority, military requirements of the Department of Defense." *Congressional Record* (20 October 1993), S13962.

handled using commercial just-in-time management concepts and tools.[9] Still, for large platforms within the traditional acquisition system, such as Navy ships, Air Force aircraft, and Army vehicles, there remains a deliberate and institutionally enforced segregation between commercial and government activities.

In the Service R&D community, however, a different view of dual-use appears to prevail. Here, it is argued that DoD invests considerable monies in capabilities that, although tuned to the needs of the military, have commercial analogs. A good example is in shipbuilding R&D, where DoD investments have yielded advances in ship control systems, propulsion, and machinery. According to the Navy, due to the superior technologies embodied in their equipment, commercial industry should be interested in taking these results and applying them in the private sector. This logic appears to break down, however, in that commercial industry has developed and fine-tuned its own technologies for the marketplace. Unless military systems demonstrate significant cost and performance advantages over existing, marketplace-supported and maintained commercial equipment, there is no incentive to adopt alternatives.

Nevertheless, federal government civil agencies in general, and NASA and Department of Energy Laboratories in particular, share the vision of spin-off held by the Service R&D establishments—in this case the commercial adoption of civilian government agency R&D results. Through Cooperative Research and Development Agreements (CRADAs), commercial firms have been able to take advantage of government facilities and technology developments, but available information offers no clear cost-effectiveness measure for the government side of such expenditures.

Converse to what the Armed Services and Civil Agencies assert, the civilian leadership of the Department of Defense identifies dual-use with the spin-on of commercial technologies and the co-development and co-production of commercial and military products in the same manufacturing facilities and on the same production lines. Here it is argued that technology development can be focused to produce dual-use results that are commercially viable (attractive) and militarily useful. Unlike the Armed Services and civil agencies, the civilian leadership of DoD appears to have a different approach to dealing with extant laboratory structures, particularly those that have outlived their

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9 See, for instance, Crock 1995, 99–100. "Defense is reengineering its $40 billion-a-year logistics system. The goal is to replace an extravagant 'just-in-case' delivery mentality with a streamlined scheme similar to the 'just-in-time' systems businesses use to shrink inventories and speed deliveries."

usefulness in the post-Cold War era; moreover, it appears to be less interested in institutional preservation than improved affordability, capability, and reduced development cycle times. Furthermore, DoD leadership understands that it can favor spin-on without threatening its underlying missions—for a civil agency demonstration of the efficacy of spin-on is equivalent to arguing that the organization is at best redundant, at worst wasteful, and probably should be abolished!

We conclude, therefore, that there is no single view of how the federal government should pursue dual-use, and that organizational constitutencies employ the term differently depending upon the goals they have in mind. An important implication of this for any overview of dual-use issues is that while we could argue one interpretation is superior to all others, this would be ingenuous. Rather, to avoid semantic baggage, we employ a generic definition throughout the remainder of this work—*dual-use refers to a product,*[10] *process, or technology which satisfies military needs while also exhibiting commercial viability in the competitive marketplace*—and rely upon context to understand the real intent behind one or another use of the term. Considerations include:

- What technical parameters bound the use of the term dual-use?
  - Does it span a spectrum from subcomponents through weapons system platforms?
  - Does it refer to research and development or finished products?
  - Does it distinguish among technologies, products, processes, and services with regard to their suitability for military and commercial use?
- Who is using the term?
  - To which constituency do they belong?
  - What are the overt and covert goals of the constituency?
  - Are there particular ideological positions being represented?
- What are the larger issues which dual-use is being employed to address?
  - Is the real issue commercial-military integration?
  - Are industrial policy issues at stake?

Having established the need to pay close attention to the context in which others use the term "dual-use," however, does not relieve us of the responsibility of offering a framework for examining potential future DoD dual-use efforts—the context of this paper as directed by study issues 4 and 5. In particular, we are interested in how the

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10 We include along with products, services.

government may programmatically pursue increased military reliance on the commercial industrial base through the expenditure of public sector funds—an activity we term *dual-use investment.* Based upon the literature reviewed and the experience of the authors, we construct four archetypal models which apply equally to technologies, products, and processes, and which could serve as vehicles for such investments.

1) **Purposeful Spin-off.** The transfer or transition of defense technologies to commercial use has been termed spin-off in the literature. Note that during the Cold War, in the U.S. spin-off was not pursued as part of an overarching goal of dual-use promotion; rather, it occurred serendipitously, as pointed out in *Beyond Spinoff.* Throughout the remainder of the paper we refer to the unplanned spin-off of military technologies as *serendipitous spin-off.* Conversely, we suggest that one potential approach for advancing the concept of dual-use is to consciously fund activities that seek commercial applications for defense capabilities, hereinafter termed *purposeful spin-off.* Note that for this to yield military benefits, it is implied that whatever is spun-off will retain sufficient military utility that it remains relevant to DoD's needs. As pointed out above, this model is generally favored by established government research and development organizations, particularly federal laboratories.

2) **Direct Spin-on.** The adoption of commercial off-the-shelf (COTS) capabilities and non-developmental items (NDIs) to meet the needs of the military is a form of spin-on we term *direct spin-on.* This approach has gained favor with the military operational communities in the past few years as defense budgets have declined and commercial technologies have rapidly advanced ahead of those available to the military. A program to promote direct spin-on would concentrate on selecting and funding the acquisition of off-the-shelf products, processes, or technologies that require little or no modification to address the mission requirements of the military.

3) **Indirect Spin-on.** A second type of spin-on activity to promote dual-use we term *indirect spin-on.* Here the approach is to fund activities in the commercial sector to influence their development into capabilities that jointly meet the needs of the military and commercial sectors. Traditionally, this has been an ARPA strategy, and its most visible application has been through that agency's Technology Reinvestment Project.[11] But while TRP is the current incarnation of this approach, DoD, acting as the initial investigator in an area of great technical promise that goes beyond the financial capacities of any commercial entity (given the attendant risk), has a history which significantly predates both the TRP and ARPA.

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[11] Appendix D offers a brief overview of ARPA history.

4) **Industrial Base Strengthening.** The final dual-use strategy we observed in the literature is one that addresses the broader role of the commercial industrial base and its importance to overall national security, both military and economic. This approach, which also has as its goal the creation of long-term, high-quality jobs for U.S. citizens, maintenance and promotion of domestically based production activities, and improved balance of payments position, in addition to the improvement of opportunities for the military to draw upon commercial capabilities, we term an *industrial base strengthening* strategy. Both the Clinton administration and Democrats in Congress support this notion of dual-use, while it is generally opposed by congressional Republicans.

In the following sections we continue our general discussion of dual-use, its "operationalization," and limits to its applicability from warfighting and mobilization perspectives. Chapters 3, 4, 5, and 6 relate our four programmatics models of dual-use to U.S. and foreign experiences from the perspective of government policy making and historical case studies.

B. OPERATIONALIZING DUAL-USE

Within a changing environment shaped by rapid innovation, classifying the "dual-usefulness" of new technologies, products, and processes, and their applications, involves exploring dynamic interrelationships, beginning with scientific discovery and extending through the manufacture and life-cycle support of finished products. In some cases, military requirements cannot be met by commercial industry or they may "contradict" commercial needs and practices. In other cases, however, commercial capabilities and military requirements may be mutually satisfied, and these instances may offer significant opportunities for DoD to leverage private sector investments to speed technology development and improve affordability through market economies. This view is by no means held universally, however.

Not everyone accepts the concept of relying on dual-use to meet military needs or the possibility of integrating military and commercial needs within a unified production and distribution environment. Some say that the differences between the two sectors are driven by product design requirements that press the limits of engineering feasibility. Some argue that labor costs in defense markets tend to be greater than in their commercial counterparts because of stringent production and administrative requirements, or that DoD production runs are too small to yield commercially viable economies of scale. And some point out that the composition of the work force in defense sectors is relatively labor intensive, composed of precision-oriented production workers, technicians, engineers, and large administrative support staffs associated with engineering-intensive work.

For others, dual-use conjures such fanciful goals as building M-1 tanks and Chevrolets on the same assembly line, or eliminating the distinction between military and commercial goods and services altogether. In the latter case, all military purchases would be from off-the-shelf commercial sources, and there would be no need to maintain any sort of military-unique production at the component level. Commercial sources and technologies would form the basis for national security.

In reality, there is a broad spectrum of dual-use possibilities between the purely military and purely commercial wherein some product and process technologies are conducive to jointly meeting the needs of the two sectors and some are not. Opportunities along this spectrum include the use of flexible manufacturing systems to co-produce military and commercial variants of the same item in the same facility, insertion of commercial items into military platforms, and investment in new technologies that are anticipated to have dual-use. Important bastions of commercial- and military-unique production will continue to exist, however, and not all intermediate dual-use opportunities will be exercised.

Figure II-1 depicts one way of thinking about changes that lead to increased military reliance on dual-use. Along the vertical axis we have a simple, four-stage model of technology development and deployment; along the horizontal axis is a continuum from purely military to purely commercial requirements. Inside the figure are three areas, one each for military-unique, commercial-unique, and dual-use products, processes, and technologies. Increased use of dual-use technological and industrial capabilities by the military is represented by a migration of the diagonal lines in the figure in the northwesterly and northeasterly directions, resulting in a shrinkage of military- and commercial-unique applicability.

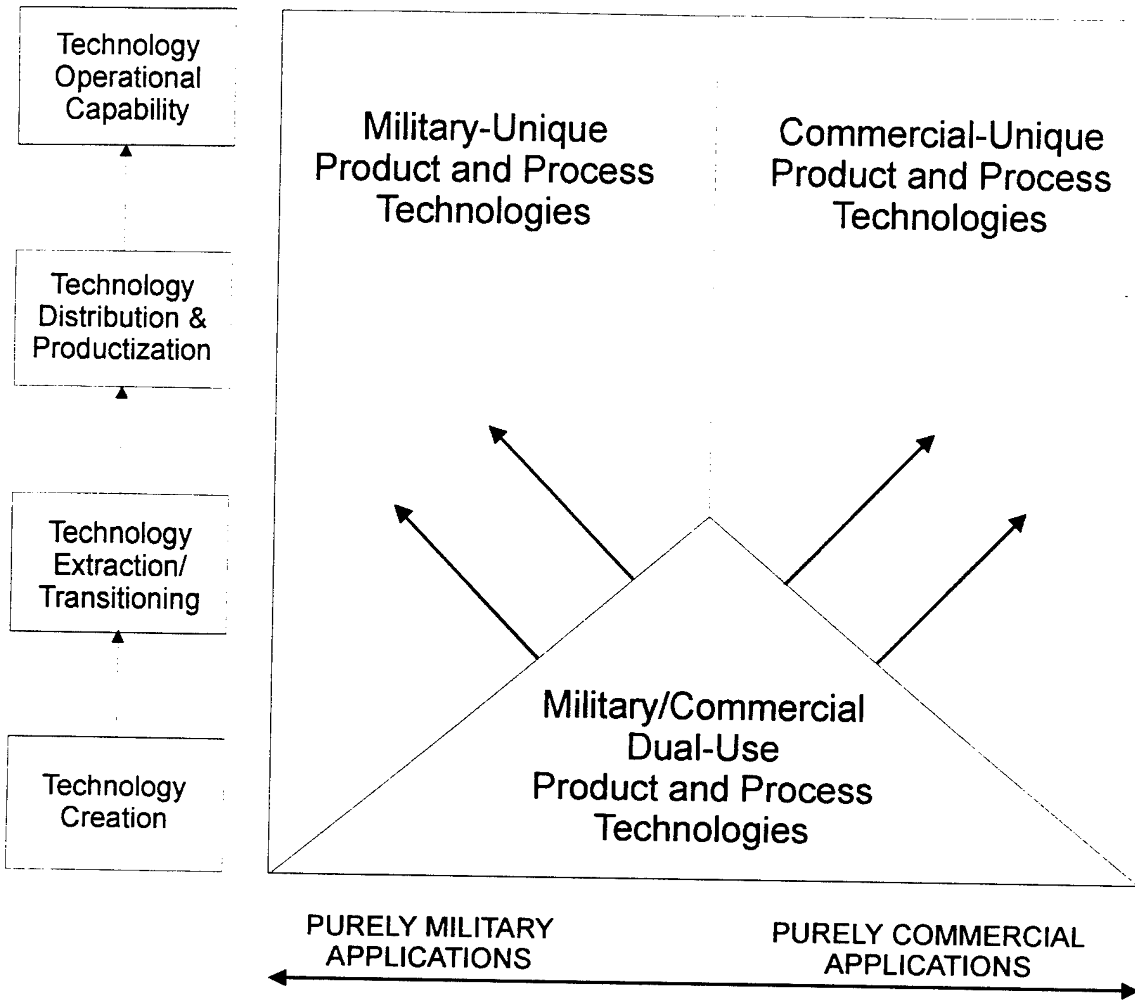

Figure II-1. Dual-Use Technology Space

For instance, the production of militarily useful components of weapons and systems on commercial lines—direct spin-on exemplified by the use of commercial electronics for the Army's Common Hardware and Software (CHS) program, which competes and qualifies commercial vendors to supply "ruggedized" versions of non-Mil-spec equipment—might be thought of as pushing the "boundaries" between commercial and dual-use in Figure II-1 to the northeast. Efforts which are under way to review and harmonize Mil-specs with commercial requirements and capabilities (which in some cases are more rigorous and modern than their military counterparts) could be seen as pushing the boundaries between military and dual-use to the northwest and creating opportunities for both direct and indirect spin-on.

There are practical limits to dual-use, however, because some military requirements are incompatible with commercial needs.[12] Within the domain of military-unique technology developments are such examples as stealth aircraft, cruise missiles, and radiation-hardened microelectronics. Reducing radar cross-sections with stealth technologies simply does not fit with commercial air transportation—"being seen" by radar is an important air traffic safety consideration. The technologies used in constructing and targeting cruise missiles may have some relationship to the development of commercial aircraft, but military uses of autonomous vehicles and of target recognition are today at best "cousins" to their commercial counterparts. The need for radiation-hardened microelectronics that can survive extreme levels of electromagnetic interference would appear to be beyond the vast majority of nonmilitary applications.

Of the military technologies serendipitously spun-off to the commercial sector, prominent are the development of microelectronics and supercomputers, commercial jet aircraft and aircraft engines, the global positioning system (GPS), and composite materials.[13] In each of these examples military requirements were close enough to their commercial counterparts to find quick acceptance in the commercial sector. In the case of microelectronics, the Defense Advanced Research Projects Agency pursued activities that led to the development of the integrated circuit for use in ballistic missile guidance systems; in the case of supercomputers, it pursued high-speed numerical calculation capabilities to assist in the design of other advanced systems and to facilitate cryptography. The Boeing 707 and 747 aircraft are derivatives of defense-funded research into new aircraft designs; global positioning satellites had their origin in the military's need for precise location and targeting information;[14] and composite materials arose from the quest for lighter, stronger airframes and armor systems but are now being used in commercial products.

We must recognize, however, that this trend of using military technologies in commercial applications is changing. In the future the private sector is expected to channel much larger investments into commercial technologies that will have increasing relevance in military applications.[15] In the United States this is already true for advanced

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[12] Velocci 1993, 56.

[13] Alic et al. 1992 provide for a comprehensive history and treatment of dual-use technologies spun-off prior to the Clinton administration.

[14] GPS is still a military system, but it is being offered for civilian use.

[15] U.S. Congress OTA 1991b, 3.

flexible manufacturing and computer-aided design, areas in which commercial industry holds a lead over the military making a strong case for dual-use through industrial base strengthening. In Japan a much smaller defense R&D budget has led to a direct spin-on of commercial technologies in lieu of custom-designed military equipment.[16] Some developing nations are also pursuing this path in an effort to attain indigenous defense industrial capabilities. Many commercial technologies currently available are comparable to the most advanced military technologies of only a decade ago, leading to medium-tech defense programs for indigenously designed armor, aircraft, and naval vessels. The Chilean Navy, for instance, will employ standard IBM computer architectures in domestically designed command and control systems aboard selected vessels in its fleet;[17] the Dutch Navy will use commercial VAX computers for similar command and control uses.[18]

While such dual applications are efficacious, they introduce significant problems relative to both domestic weapons producibility and the international proliferation of such capabilities. German and Japanese machine tools, Japanese robotics, and other foreign equipment and processes are today required to deliver U.S. weapon systems. In a variety of cases where foreign manufacturing techniques are superior to those found in the United States, the U.S. military will need additional foreign know-how if it is to improve quality and reduce costs in the future. In fact, the trend in the United States today is toward increased use of a mixture of foreign and domestic manufacturing technologies to support the defense industrial base.[19]

Therefore, while dual-use may be seen as essential to restructuring the U.S. industrial base so that commercial sources may be used to meet military needs, it is also bringing the military closer to commercial practices that continually realign with global competitive realities. Even if the United States uses only domestic components and materials, it will not be assured freedom from foreign process technologies. Attaining and maintaining a world-class military in the future will increasingly become a global endeavor leading to a concomitant spread of militarily useful technologies and know-

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16 U.S. Congress OTA 1991, 42–43.

17 *Jane's Defense Weekly*, 21 March 1992, 467.

18 Janssenhok 1992, 443. Even so, the capabilities of computer hardware are and will remain a function of software, and the majority of this which is useful to the military is likely to remain defense-specific.

19 See, for instance, National Academy Press 1991, 40–42.

how. This will be equally true for the unique requirements of the military that will not easily conform to those of the private sector, such as for large platforms (e.g., submarines and stealth aircraft).

C. MEETING DEFENSE REQUIREMENTS WITH DOD DUAL-USE INVESTMENTS

From the point of view of the current civilian leadership in DoD, dual-use investments are made primarily to further national security, although the Clinton administration maintains the need for such investments to have broader economic benefits as well. This emphasis focuses such investments on the issue of providing a future, integrated industrial base that is capable of maintaining a world-class U.S. military. A key question is how well can such investments and facilities support weapon system production, or "how much can be delivered and when?" Any honest investigation of this question must acknowledge that it is no simple task to determine the exact time or industrial base resources required to produce modern weapon systems, high-tech or not. When addressing the issue of dual-use the answer is particularly elusive because the resources and technologies that will be available from an integrated industrial base are as yet unknown and impossible to project. Furthermore, even with increased reliance on dual-use items and capabilities, there will remain a need to stockpile weapons and materiel—a commercial-type just-in-time system does not accommodate surge military requirements.

1. The Desert Storm Experience

The Desert Shield/Storm experience teaches that in the case of short conflict warning times it is unlikely that demands for high-tech weapons systems will be met by peacetime production capabilities, regardless of the extent of dual-use opportunities in the industrial base. The U.S. military will still need to maintain large stockpiles of moderate and long lead time weapon systems in quantities anticipated to be sufficient for "worst case" conflict scenarios. The Desert Storm experience provides some notion of the size of such stockpiles. As reported in the *Conduct of the War Report*, threat item[20] usage during Operation Desert Storm (ODS) far exceeded the authors' estimates of the peace-time ability of the defense industrial base to respond with new deliveries (see Table II-1).

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20 Weapons systems such as guided missiles and laser-guided bombs.

Table II-1. Selected Desert Storm Threat Item Usage

Item	Desert Storm Usage	Max. Production/ Month[a]
Multiple Launch Rocket System	9,660	6,000
Maverick (AGM-65)	5,100	125
Air Launched Cruise Missiles	35	10
Sea Launched Cruise Missiles	288	54

Source: Department of Defense 1992, 753–787. "Usage" refers to total use during Desert Storm.

[a] Monthly rate based upon observed peak peacetime annual procurement rates taken from the U.S. Missile Data Book, Data Search Associates 1994, 2-1 to 2-40.

Data in Table II-2, also taken from the *Conduct of the War Report*, offers another view of the "ramp-up" time for a variety of items—none of which may be considered high-tech. The report states that for more complex weapon systems, such as the AH-64 Apache attack helicopter, at least 19 months would be required to move from a production rate of six to eight units per month.[21] Furthermore, the report cites no instance in which the *production* of high technology weapon systems was "surged," perhaps an indication of the immense difficulty of doing so. (Depot maintenance and overhaul of systems, however, were surged.)[22]

We should therefore look askance at stories reporting the apparent "miraculous" design and delivery of new weapon systems in short periods of time prior to or during a war. In most cases anecdotes such as these refer to the modification of existing weapon systems, the adaptation of off-the-shelf commercial capabilities for military use, and unique heroics that must be regarded as exception rather than rule. Two of the most prominent examples during Desert Shield and Desert Storm were the acceleration of deliveries for the PAC-2 Patriot air defense missile and the development of the GBU-28 "bunker busting" PGM. Both cases are examples of so-called work-arounds.

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[21] Department of Defense 1992, 433.

[22] Ibid., 432–435.

Table II-2. Selected Surge Production Capacities

Item	Pre-ODS Production per month (000)	Maximum Capacity per month (000)	Time to Reach Maximum Capacity (months)
Desert Battle Dress Uniform Coat	0	446	9
Desert Boot	0	157	8
Chemical Protective Suit	33	200	9
Nerve Agent Injectors	60	717	8
Sandbags	84	326	6
Tray-Pack Rations	1.3*	4.7*	9

Source: DoD 1992b, 434.

*Millions of meals

In the case of the Patriot, Raytheon delivered over 600 PAC-2 missiles within the 6-month period prior to Desert Storm. These variants of the weapon were essential to provide anti-ballistic missile protection from Iraqi SCUDs for ground troops and installations. Raytheon's effort was commendable: bureaucratic production restrictions were relaxed; not all of the missiles delivered were "newly" produced but were weapons in the existing inventory that were modified with new software and warheads; while others were produced by a German company, MBB.[23]

For a true example of "necessity as the mother of invention," we cite the GBU-28. It resulted from the recognition that existing threat items were incapable of defeating the protection of some Iraqi command bunkers. To achieve a weapon with sufficient mass to afford necessary penetration capabilities, 8-inch artillery gun barrels were paired with laser-guided munitions "kits" and certified for use within a 27-day period.[24] Hence, a very specific capability gap was filled in short order.

More generally, work done for the U.S. Department of Defense to assess industrial mobilization capabilities confirms the inflexibility of weapon systems production environments. Table II-3 estimates the time required to produce a variety of modern, high technology weapon systems such as precision guided munitions ("smart bombs"), fighter aircraft, and naval vessels. For groups of "similar" weapon systems

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23 United States Army 1993, 71–73.

24 Department of Defense April 1992, 165–166.

manufactured under peacetime production conditions, the table summarizes the time between when an order for an additional increment of production for a weapon system is placed with a prime contractor, and when that additional unit is completed and available. It suggests that if the warning time prior to a conflict is short, the quantity of newly produced high technology weapons systems that will be available will not be significant under a regime of peacetime production.

Table II-3. Industrial Lead Time Estimates

General Category	Lead Time (months)
Missiles and Torpedoes	10 to 48
Rotary Aircraft	20 to 44
Fixed-Wing Aircraft	36 to 60
Ships (Ex. Aircraft Carriers and Submarines)	48 to 60
Aircraft Carriers and Submarines	72 to 84

Source: White et al., 1992.

Note: These lead times represent the peacetime period required to produce an additional unit of output within each of the categories, assuming that "warm" production facilities exist (e.g., an additional helicopter takes 20 to 44 months to deliver from the time it is ordered). Of course, these lead times could be reduced somewhat during wartime mobilization, but it is unlikely that such reductions would offer any real advantages in a war of short duration with little lead time.

2. Dual-Use Opportunities

Although the need for long lead times in defense production is likely to continue, shorter weapon system design/development/production cycles may be possible, and it may be feasible to insert dual-use technologies into platforms and weapon systems. Advances in the design, manufacture, and servicing of both commercial and defense products in the past several decades foreshadow potentially significant changes for production capabilities. Today, for instance, the so-called envelope of flexibility that defines the types of products that may be co-produced on a single assembly line is quite rigid or constrained. In the future, increased flexibility may allow the simultaneous production of defense and commercial goods on the same line. Indeed, advances in both weapon system and manufacturing simulation capabilities portend greater concurrence in product and process design and engineering, leading to significant reductions in the time required to bring new ideas out of research into existence. Even today, DoD could seize upon existing possibilities for "decoupling" production lot size and unit cost to allow sequential production of commercial and military variants of products.

The need to plan well in advance for dual-use also has particularly important implications for weapon system affordability. Design changes after the R&D stage that are not met by concomitant capabilities in production or final assembly are extremely costly. Given that some current commercial technologies are being considered for incorporation into military systems, and that new commercial technologies are being designed and developed for dual-use, the military will have to embrace such principles as concurrent engineering, flexible and agile manufacturing, and the virtual organization of design, development, and production. (The bibliography in Appendix E contains several sources on these principles.)

Furthermore, if current trends continue, there is no guarantee that geographic proximity will be the norm for commercial operations. Advanced engineering design tools capable of supporting "virtual" design activities independent of location are a reality in many private sector endeavors (and some military ones as well). Such capabilities must be leveraged to promote the coordination necessary to develop dual-use systems. As a result, government and industry will have greater opportunities for "joint" learning, as in the case of Boeing's new "paperless" design of the 777 passenger aircraft, where earlier company experience with design automation on the B-2 bomber project has been advanced to a new state of the art.[25]

Thus, successful development of dual-use capabilities in support of national security and military missions will require improved information "flow" and coordination. For instance, to achieve co-production, military requirements must be integrated into commercial decision-making processes at the earliest possible stage and must be consistent with the following four principles:

1) Commercial firms must have sufficient lead-time to be able to assess the costs and earnings potential of co-production activities.
2) Co-production should neither modify commercial products in a manner that diminishes their market acceptance, nor detract from a firm's ability to export products or otherwise compete in the global marketplace.

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[25] Stix 1991, 110. Yang 1991, 120. Also see a collection of articles on the "rollout" of the 777 in *Aviation Week and Space Technology*, April 11, 1994.

3) Military requirements must be flexible enough to accommodate emerging, fast-changing commercial approaches to product/process definition, design, development, production, and distribution.

4) The military must operate more openly, particularly where the costs of maintaining secrecy clearly outweighs the potential benefits from commercial approaches.

In short, commercial and DoD interests must "intersect" earlier—at the advanced engineering and applied research stages of product/process development—rather than at the late product development and direct commercial purchase stages, as they do now. (See Figure II-2.)

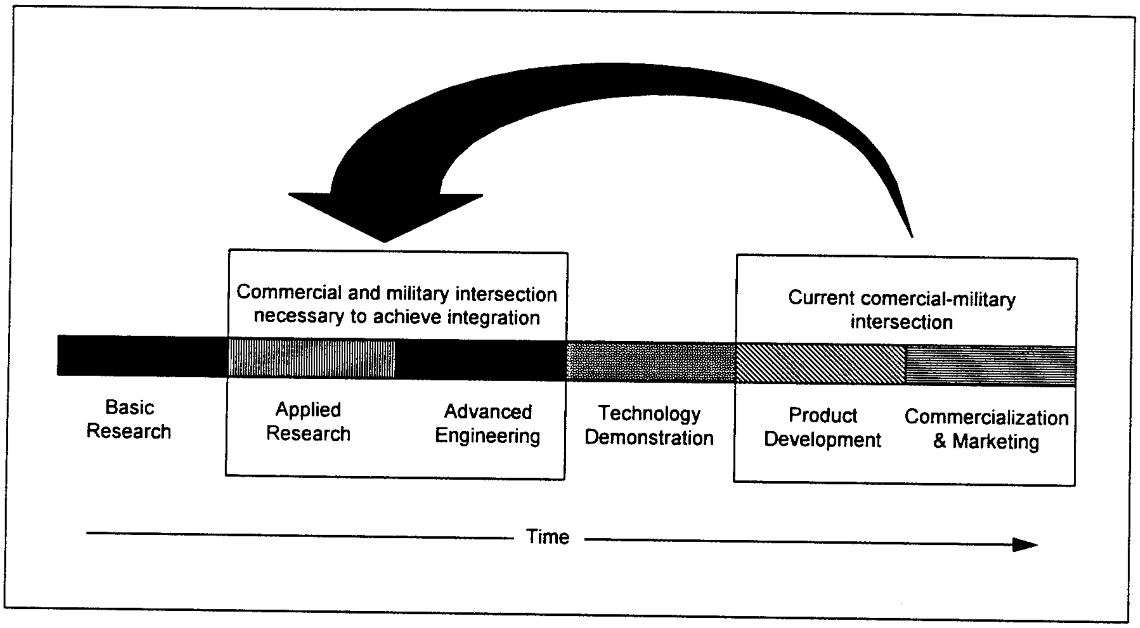

Figure II-2. Shift in Emphasis to Achieve Commercial-Military Integration

Ideally, to achieve the strategic positioning necessary for such future co-production activities we need to promote development of dual-use products, processes, and technologies *today*. Since results must be acceptable and competitive commercially before they can become available at a low cost to the military, public expenditures must be focused where commercial leverage will be greatest in reducing defense outlays. In other words, commercial interest must be channeled into dual-use activities that have both a high probability of commercial success *and* potential to significantly reduce costs for DoD procurement. Conversely, DoD must be more innovative in taking advantage of technology streams already in motion, and it must be open to the distinct possibility that it will not be able to "manage" the technology creation and dissemination process as it unfolds.

Reliance on dual-use for weapons systems/components must therefore be based on the availability of commercially viable, cost-effective, timely process technologies. The determining factor for success will be the extent to which the DoD procurement system is able to accommodate commercial approaches to doing business. Success in this endeavor will come only when DoD procurement is managed according to commercial competitive exigencies:[26] design and production activities must become more efficient and cost-effective at the same rate for both sectors. This will require concurrence in the design, development, production, and deployment of both commercial and military product and process technologies.

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[26] See, in particular, Womack, Roos, and Jones 1990, where the authors amply demonstrate the importance of operating within the correct "competitive paradigm." They contend that two different ways of managing production arose after the World War II. One, based on the pre-war philosophies of Ford and Sloane and dubbed "mass production," is characteristic of businesses in the United States and Europe. This is the traditional assembly line approach to enterprise management and the use of production technologies exemplified by the "big-three" U.S. auto makers prior to the late 1980s. The other, originating in Japan, is termed "lean" production and is exemplified by Japanese auto manufacturers.

Lean production encompasses changes in the management of productive enterprises that reduce costs, increase quality, and improve efficiency, such as just-in-time inventory control, flexible manufacturing, worker empowerment, reduction in waste and scrap, adoption of statistical process control techniques, and decoupling of price and quantity in production. Many "programs" aimed at achieving such goals in the West are now being adopted, such as Total Quality Management (TQM), Total Quality Control (TQC), and concurrent engineering (CE). It is noteworthy that the Department of Defense has attempted to adopt, and in some instances has been a pioneer in applying, lean principles. Recently, the U.S. Air Force announced a study of its own, the "Lean Aircraft Initiative," to pursue lean production for military aircraft. Significant goals for U.S. security are to develop "quality products in a shorter time and at lower costs," and to acquire information on how to reform the acquisition system. *Aviation Week and Space Technology*, May 24, 1993, 23–24.

Prevailing commercial "best practices," such as lean production, will therefore have to extend to all aspects of defense acquisition if the true potential for commercial-military integration is to be realized. The real issue is whether defense acquisition practices will ever be able to adjust quickly enough to changes in the private marketplace to harmonize military needs with commercial opportunities. To achieve such integration it will be crucial that the management philosophies of the Department of Defense reflect commercial realities. Otherwise, firms catering to the private sector will not be willing to participate in co-production activities because they will represent a "drag" on operations and profitability.

3. Limitations on DoD Dual-Use Reliance

Even if all of the potential offered by lean, flexible, and ultimately agile manufacturing practices is realized, expectations about the future must be realistic. Weapon production lead times are longer today than in the past because of the complexity of systems and platforms. Even with state-of-the-art production processes, production times are still likely to be lengthy when pushing the envelope of new technologies. Furthermore, while flexibility in production may become a reality for many items, the scale of many militarily unique production facilities—for weapon systems not amenable to civilian co-production—will limit the number that may be produced over any given period of time. Thus, no matter how rapidly work-arounds and other quick reactions have been accomplished in the past, we cannot conclude that the United States should rely on potentially serendipitous forms of preparation for war. Rather, quick turnaround successes suggest that there is more flexibility in both the procurement and industrial mobilization processes than generally believed, and that this should be part of the vision of the integrated dual-use industrial base.

Assuming that the restrictive rules and regulations governing defense acquisition are surmounted—and this is a major assumption—it is clear that unique military requirements that cannot be met through commercial or dual-use channels will remain, even if we are completely "successful" in promoting dual-use. The issue confronting DoD, therefore, is not how to achieve complete dependence upon commercial sources, but what represents a prudent mixture of industrial resources from a national security point of view, as well as how to promote the desired mix. To find the answer, DoD will need to develop dual-use criteria and measures of merit that can be used to pursue clearly defined program objectives.

Once we accept the premise that complete commercial dependence is out of the question, the next task is to clarify what constitutes prudent commercial reliance. This clarification, in turn, is bounded by what will ultimately be acceptable to commercial firms doing business with DoD. Clear and undisputed evidence has shown that the motivations for private and public sector investments in technologies, products, processes, and services differ significantly.

The real issue, therefore, is not about technology itself, but the way in which we will seek to apply it to military needs in the future. If the ultimate goal is to rely more heavily on commercial industrial capabilities, DoD must be willing to accept all that this entails, including commercial design, development, accounting, personnel, and other practices. This is central to the success of dual-use since commercial firms will not voluntarily participate in integration efforts if DoD requirements represent a drag on their operations.

Successful integration will also require an openness to altogether new approaches. For instance, it may become more efficient to design and construct weapon system platforms jointly with other nations, but to outfit them with weapons and systems unique to the U.S. military. One could imagine common vehicle designs with armament supplied by national firms. While unlikely for political reasons, such an approach would mirror the current commercial trend toward outsourcing and would allow U.S. defense dollars to be concentrated on unique, force-multiplying technologies to maintain a qualitative edge.

Dual-use is most likely to take hold where shrinking defense budgets force changes in attitudes and opportunities to allow DoD to adopt commercial practices: off-the-shelf commercial components and co-produced items, reliance on commercially viable process technologies, and adoption of commercial management philosophies.

We will know the limits of dual-use through the willingness of private sector enterprises to engage in a process that yields items useful to both sectors. Where the anticipated profitability of designing and producing a military item along with a commercial item yields at least the same return on investment as producing the commercial item alone, both may be pursued; where the return on investment is reduced by the inclusion of military requirements, only the commercial item will be pursued.

D. SUMMARY

- The term "dual-use" conveys many different meanings and is endowed with passionate overtones by constituencies with competing institutional and political objectives. As such, it is more useful to understand how the term is employed rather than to pin down any one, universally acceptable definition.
- The government has used four approaches to implement dual-use. *Purposeful spin-off* consciously funds activities that seek commercial applications for defense capabilities. *Direct spin-on* involves the adoption of commercial-off-the-shelf (COTS) and non-developmental item (NDI) capabilities by the military. *Indirect spin-on* funds activities in the commercial sector to influence their development into capabilities that jointly meet the needs of the military and commercial sectors. *Industrial base strengthening* seeks to create long-term, high-quality jobs for U.S. citizens, to maintain and promote domestically based production activities, and to

improve the nation's balance of payments position, in addition to exploiting opportunities for the military to draw upon the commercial technology and industrial base.

- Despite the purported benefits of dual-use, there are practical limits to the degree that it may be pursued. In some cases, military requirements are incompatible with commercial needs and practices. For instance, if the warning time prior to a conflict is short, the quantity of newly produced high technology weapon systems that will be available will not be significant under a regime of peacetime production. Consequently, more traditional approaches to stockpiling and maintaining materiel reserves will continue to be central to national security.
- Although many have posited significant potential for spinning-off military technologies for commercial use, today most military technologies have few if any commercial analogs or applications. In fact, future investments in commercial technologies by the private sector are expected to be increasingly relevant for military applications; thus, spin-on (direct and indirect) is the more likely route for dual-use.
- Because commercial enterprise is rapidly becoming globally integrated, entwining commercial and military technologies introduces new issues regarding the domestic producibility of weapons systems and the international proliferation of advanced military capabilities.
- To achieve co-production, commercial and DoD interests must "intersect" earlier—at the advanced engineering and applied research stages of product/process development—rather than at the late product development and direct commercial purchase stages, as they now do. Thus, it is necessary to plan well in advance for dual-usefulness, not only to promote rapid application of advanced technologies, but, more importantly, to make weapon systems affordable. Design changes after the R&D stage that are not met by concomitant capabilities in production or final assembly are extremely expensive.
- Ultimately, success with dual-use will require DoD to "think outside of the box." This will include changing the procurement system so that it is more adaptable to commercial business approaches and opportunities.

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III. U.S. TECHNOLOGY AND DUAL-USE POLICY SINCE WORLD WAR II

The policy issues surrounding dual-use investments grow out of a much larger, partisan debate over the appropriate role of government in fostering economic growth and development. It is often said that during the Cold War the United States pursued a de facto industrial policy through the Department of Defense, using research, development, and procurement expenditures for both national security and economic purposes. In this chapter we briefly review the history of U.S. industrial and technology policies and relate them to the emergence in the late 1980s of a conscious pursuit of dual-use programs and the Technology Reinvestment Project (TRP).

A. HISTORICAL OVERVIEW OF U.S. TECHNOLOGY POLICY

Prior to World War II, and in particular prior to the Great Depression, intervention by the U.S. government in economic affairs could best be described as "infrastructural." Programs supported by the government generally involved the development and production of "public" goods such as canals, harbors, railroads, highways, education, and defense. The closest that the nation came to a technology policy per se was probably in the highly successful agricultural extension programs that were designed to impart useful knowledge to assist the agricultural sector.

The Great Depression was a watershed for U.S. government intervention in the marketplace. Although slow in coming, public works programs and pump-priming industrial policies—Keynesianism—proved an effective way of reviving the national economy. The role of government in resuscitating the economy was more forcefully demonstrated by World War II—the war economy cogently pointed to the positive effect of government intervention (in the extreme) on the nation's productive potential. In particular, this period of U.S. history demonstrated the relationship between economic growth and high levels of savings and investment (albeit enforced). In the post-war era, the U.S. continued its pursuit of Keynesian policies, focusing primarily on attempts to minimize the impact of economic cycles on business and productivity. The support of national security goals through military means, intentionally or not, played an important part in such policies.

The success of the Office of Scientific Research and Development (OSRD) during World War II is seen by most as the fount of post-war interest in science and technology investments to further social goals. Vannevar Bush, who led OSRD during the war, proposed to President Roosevelt that a "National Research Foundation"[1] (NRF) be established after the war to capitalize on advances in science and technology funded as a result of the conflict, and to keep alive these important activities. He believed that science, in particular, could serve "as a powerful factor in our national welfare," but stipulated the prerequisite that "applied research in both Government and industry must be vigorous."[2] Moreover, Bush said, the NRF "should promote a national policy for scientific research and scientific education, should support basic research in nonprofit organizations, should develop scientific talent in American youth by means of scholarships and fellowships, and should by contract and otherwise support long-range research on military matters."[3] Unlike the present structure of research and development in the United States today, the NRF was envisioned as an all-encompassing organization with separate divisions focusing on civilian and defense needs.

While the unified structure of the NRF was ultimately rejected, Bush's advocacy did result in the establishment of the National Science Foundation (NSF) to focus on basic research; other departments and agencies took on mission-specific R&D investments. In 1958 the National Aeronautics and Space Administration and the Advanced Research Projects Agency were established to pursue civil and military uses of space, respectively; an Atomic Energy Commission, and later the Department of Energy, took on the onus of researching and building nuclear arms; environmental research and protection agencies such as the National Oceanic and Atmospheric Administration and the Environmental Protection Agency were established in the 1970s. Throughout the 1960s, 1970s, and 1980s, U.S. public sector expenditure on all research and development activities grew rapidly in nominal terms, although much more modestly in real terms, as shown in Figure III-1.

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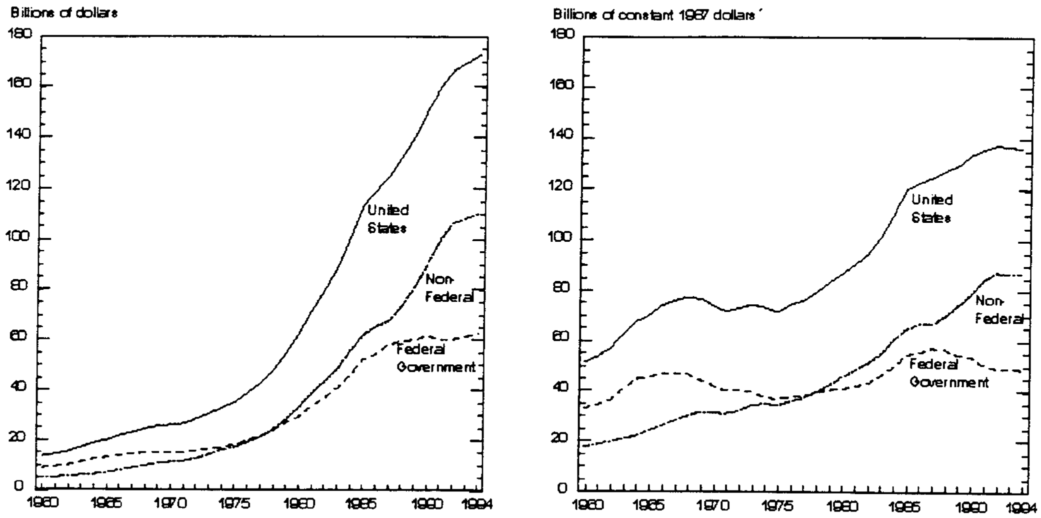
1 Bush 1945, 34.

2 Ibid., 7.

3 Ibid., 34.



Source: National Science Foundation

Figure III-1. U.S. Research and Development Expenditures, 1960 to 1994

Despite such massive public sector funding levels for R&D in the United States, the nation's significant scientific and technological lead over other countries eroded in the decades of the Cold War. Findings of the National Academies of Science and Engineering, and of various economic competitiveness studies, appeared in the 1980s following mounting concerns regarding "declining industries" and slowing productivity growth rates earlier in the decade. The connection between economics, technology, and national security became the subject of substantial discussion and controversy within the public policy arena. A wide range of private sector groups, Congress, and the executive branch rethought and reformulated basic policies and programs concerning how the technology base could maintain both the economic and military security of the United States. These efforts produced a variety of private sector and public institution studies, numerous government reports, and considerable congressional legislation aimed at greater focus on and funding of explicit technology concerns.[4] For instance, Congress mandated that in 1989 DoD begin producing an annual *Defense Critical Technologies Plan*, and that beginning in 1991 the Executive Branch begin producing a biannual

4 This legislation includes the National Manufacturing Technologies Act, the National Critical Technologies Act, and specific provisions of the Defense Authorization Act, much of which concentrates on the transfer of technology into applications and support for manufacturing.

National Critical Technologies Report to explain where government technology efforts are headed and how public resources are to be applied.[5]

In response to mounting pressure from the scientific and technical communities in industry and academia to review the fundamental role of government in maintaining and promoting national technology and commercial interests, the Bush administration, in September 1990, issued the first-ever *U.S. Technology Policy*.[6] In this document, the administration explicitly supported technology development in the United States for the purpose of promoting the economic competitiveness and overall security of the nation. For the first time in U.S. history concerns within the executive branch, the Congress, industry, and academia spoke with a single voice about the need to reassess and redress shortcomings in the nation's ability to maintain its strong competitive standing in the world economy. However, rather than call for direct government intervention in the marketplace, this document reserved a role for support only of so-called pre-competitive and generic technology investments to maintain a "level playing field."

Despite its limited scope, the Bush Technology Policy elicited a host of recommendations for its implementation, including a variety or reports and papers released by public and private organizations such as the National Academies of Sciences and Engineering, the Competitiveness Policy Council, and the Carnegie Commission on Science, Technology and Government. The following key recommendations were made in these reports:

> **Change DARPA to NARPA.** In September 1991, the independent Carnegie Commission on Science, Technology and Government issued findings and recommendations which directly called for refocusing government programs and priorities to foster a "national technology base."[7] This report emphasized

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5 Department of Defense 1993, D-2–D-4. In fiscal years 1991 and 1992, Congress appropriated $50 million and $60 million, respectively, for use in "Precompetitive Technology Consortia" by the Defense Advanced Research Projects Agency (DARPA) to pursue promising technologies with military applications within the commercial sector. FY 1991 monies funded eight precompetitive consortia: the Ceramic Fiber Consortium, the Advanced Composites Technology Consortium, the Optical Network Technology Consortium, the Optoelectronics Technology Consortium, the Advanced Static Random Access Memory project, the Linguistic Data Consortium, and the Superconducting Electronics Consortium. FY 1992 monies funded six precompetitive consortia: the DRAM Capacitor Materials Consortium, the Data Storage Consortium, the Electro-Magnetic Code Consortium, the Micromagnetic Components Consortium, the Precision Investment Casting Consortium, and the Ultra-fast, All-Optical Communication System Consortium.

6 Executive Office of the President 1990.

7 Carnegie Commission on Science, Technology, and Government 1991, 10.

the connection between national technological advancement and the economic well-being of the country, and explicitly called for redefining defense technology development activities and concerns. It specifically recommended transforming the *Defense* Advanced Research Projects Agency into the *National* Advanced Research Projects Agency.

Develop a Competitiveness Strategy and Monitor Foreign Developments. In March 1992, the Competitiveness Policy Council issued *Building a Competitive America*, in which it called for "developing a 'competitiveness strategy' through both sector-specific and generic policies." It also called for "monitoring the activities of foreign governments and firms" in industries that are important to the "prosperity" of the nation, and a potential role for the intelligence community in this activity.[8]

Establish a Civilian Technology Corporation and Direct DARPA Efforts More Towards Dual-Use Technologies. The National Academies of Sciences and Engineering report, *The Government Role in Civilian Technology: Building a New Alliance*, offered a clear and concise conception of potential government policies to promote national technology competitiveness, including a new recommendation for government to establish a Civilian Technology Corporation to undertake investments in pre-competitive technologies that are seen to have a high social value but too low a private rate of return to be undertaken by commercial firms. It also recommended "that DARPA's traditional role in dual-use technology be reaffirmed."[9]

In addition to the significant body of literature cited above regarding U.S. competitiveness, the Office of Technology Assessment published (until its demise in October 1995) a penetrating series of reports on the defense industrial base, defense conversion, and civil-military integration. The Center for Strategic and International Studies was commissioned to produce reports on defense conversion issues and the integration of defense and commercial technologies. A DoD Defense Conversion Commission investigated potential affects from declining defense expenditures. And the Carnegie Commission on Science, Technology, and Government issued several reports on the state of the national and defense technology base.

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8 Competitiveness Policy Council 1992, 32–33.

9 National Academies of Science and Technology 1992, 63.

B. PRE-TRP DUAL-USE POLICIES IN THE DEPARTMENT OF DEFENSE

For DoD, dual-use programs are a means to implement its post-Cold War strategy of taking advantage of the most advanced commercially available technologies while also making weapon systems more affordable by relying on cutting-edge commercial technologies.[10] When viewed from this vantage point, the success of dual-use policies and programs becomes virtually inseparable from overall acquisition reform issues. Indeed, acquisition reform must be addressed as a significant factor in the potential structure and success of any dual-use effort.

Beginning in the early 1970s there was a growing angst in the Defense R&D community about what today is known as the Defense Technology Base.[11] This concern derived partially from the fragmenting of DoD-university relationships that occurred during the Vietnam War, and partially from the heavy focus on acquiring weapons for the war effort—R&D for the war overshadowed longer term research. In addition there were concerns that many of the Defense R&D organizations that had evolved during and as a result of World War II and the Cold War had outlived their usefulness.[12]

Beginning in the mid-1970s, a number of relatively discrete DoD studies appeared (with several emanating from the Defense Science Board) on the topics of technology security and export control, international technology cooperation, defense technology base support, mobilization and surge capabilities, foreign source dependency, and growing concerns that DoD laboratories were rapidly becoming ineffective. From 1975 to the present, the effectiveness of DoD's technology investment and the overall strength of the base upon which defense technology is developed has continually attracted both executive branch and congressional review.

By the early 1980s, declining U.S. industrial competitiveness emerged as the central issue for defense industry foreign dependence. It was not until the 1984–85 time frame, however, that the link between economic competitiveness, technological competence, and national security was explicitly highlighted in public discussion. A catalyst for this focus was the Report of the President's Commission on Industrial Competitiveness, *Global Competition: The New Reality*. From this point through the

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10 Perry 1994, 8–9.

11 More recently the Office of Technology Assessment has used the phrase "Defense Technology and Industrial Base," or DTIB.

12 Some felt that these institutions had lost focus and were rapidly becoming moribund.

remainder of the decade, a widely accepted set of recommendations began to emerge. Underlying this dynamic was a growing appreciation of fundamental changes occurring in the world in three major domains—geopolitics, economics, and technology.

As discussed in the preceding section, this was a period of studies, analyses, and assessments of "technological erosion," "declining competitiveness," "foreign dependency," and "critical technologies." At the same time, DoD had some difficulty addressing the scope, magnitude, and overall ramifications of issues underlying technological competitiveness, and in systematically defining and pursuing DoD policies and strategies for dealing with them.

In particular, our review of the literature identified the following set of relatively distinct issue areas that, in the 1980s, converged on the broader subject of technological competitiveness which are relevant to an examenation of dual-use: (1) the economic plight of specific commercial industries; (2) particular DoD "technology base" concerns regarding its Defense laboratories; (3) DoD's general approach to allocating "basic" R&D resources; and, (4) concerns regarding the ability to mobilize and surge the "Defense industrial base."

The significance of declining overall U.S. industrial competitiveness for Defense industry and national security was highlighted in several DSB Task Force reports issued throughout 1980s. In particular, the 1987 DSB *Task Force on Semiconductor Dependency* explicitly recommended increased government funding for the semiconductor industry to stem the erosion of U.S. worldwide market share, and the establishment of various initiatives to bring together government, industry, and academia to promote "joint action on the problems of semiconductor research."[13] A 1988 DSB report on *The Defense Industrial and Technology Base* found that "globalization of U.S. defense markets has made our nation partially and irreversibly dependent upon foreign sources" as a result of "a pattern of inadequate long-term investment by prime and subtier suppliers."[14] In the same report an explicit recommendation is made to link economic and national security policies: "The Secretary of Defense should take an active role in formation of national economic policies (to include tax and trade) that affect national security capabilities."[15]

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[13] U. S. Department of Defense 1987, 11–13.

[14] U. S. Department of Defense 1988a, 2.

[15] Ibid., 4.

In the mid-1980s, DoD was also waking up to the "Reagan revolution" with the release in 1986 of the Packard Commission report, *A Quest for Excellence*. The report included the following recommendations:

> Rather than relying on excessively rigid military specifications, DoD should make much greater use of components, systems, and services available "off the shelf." It should develop new or custom-made items only when it has been established that those readily available are clearly inadequate to meet military requirements.
>
> To promote innovation, the role of the Defense Advanced Research Projects Agency should be expanded to include prototyping and other advanced development work on joint programs and in areas not adequately emphasized by the Services.
>
> Federal law and DoD regulations should provide for substantially increased use of commercial-style competition, relying on inherent market forces instead of governmental intervention. To be truly effective such competition should emphasize quality and established performance as well as price, particularly for R&D and for professional services.[16]

Appendix H of the report contains an important discussion of the legal remedies and strategies for implementing many of the report's recommendations. We address this topic in Chapter VII.

The year 1986 marked the first time in the Reagan presidency that the DoD budget declined in real terms. While it is difficult to assign causality, in that same year the under secretary of defense for acquisition, Dr. Robert Costello, began a series of efforts that were to link directly the issues of industrial competitiveness and national security.[17] One thrust was to create an industry-government Forum on Defense Manufacturing entitled *Rethinking DoD's Manufacturing Improvement Strategies*. In early 1987, the deliberations of this forum and its industry-led working groups provided a broad set of inputs to the under secretary of defense for acquisition, who then formulated *Bolstering Defense Industrial Competitiveness: Preserving Our Heritage*. In many ways

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16 Blue Ribbon Commission on Defense Management 1986, xxv–xxvi.

17 The spin-off side of dual-use, of course, had a long lineage. In *The Relations between Defence and Civil Technologies* (edited by Gummet and Reppy), a collection of essays on spin-off and commercial reliance published by NATO in 1988, leading authorities on the defense industrial base in the United States and Europe explored the history and derivative commercial benefits from military investments.

this document represented a watershed of ideas for increasing military reliance on commercial capabilities.

> By itself, the Department of Defense is incapable of sustaining the industrial base upon which it depends. American industry must, of its own volition, remain commercially competitive in today's world economy. The Department, however, can participate in or lead activities that bolster American industrial competitiveness in world markets while ensuring industry's ability to assume a direct role in supporting our combat requirements.[18]

After reviewing this report, we conclude that it articulated, for the first time, a coherent perspective and a comprehensive strategy regarding defense and overall national industrial competitiveness. This strategy incorporated previous DSB recommendations on the industrial and technology base, and established several thrusts for implementing and carrying forward the strategy. Included were the establishment of the Defense Manufacturing Board, the creation of a Defense Manufacturing Strategy committee by the National Academy of Sciences,[19] and the establishment of a new position of Production Base Advocate with "broad authority to deviate from acquisition regulation (both legislative and administrative based) in the process of conducting experimental programs to improve Department of Defense Management."[20]

Despite its plusses, the "Costello" report, as it became known, and its broad programmatic view regarding Defense interest in industrial competitiveness, did not survive the change in executive branch administrations that took place in 1988. Most of the initiatives that were recommended or enacted were largely ignored, and some were explicitly canceled. The Defense Manufacturing Board was merged into the Defense Science Board, DARPA sponsorship of research in some of the more broadly scoped technology areas (e.g., High Definition Systems and Manufacturing Technologies) came under increasing scrutiny, and the role of DoD in broader issues of industrial competitiveness and manufacturing technology was circumscribed.[21]

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18 Department of Defense 1988b, iii.

19 Ibid., 40–41.

20 Ibid., 45.

21 It is worth noting that Costello did not give up on his vision, and in 1992 co-authored *Regaining U.S. Manufacturing Leadership*, in which he argues in favor of dual-use policies as well as a DARPA/NARPA outside of DoD. Costello and Ernst 1992, 114–116.

Nevertheless, there was an active discussion of the spin-on side of dual-use technologies in the 1989 Defense Science Board Report, *Use of Commercial Components in Military Equipment*, which concludes that "the Defense Department can do much more to reap the benefits available for greater use of commercial products and commercial buying practices," and that "the Secretary of Defense [should] establish [a] commercialization program as a 'flag ship' in the overall efforts at acquisition reform."[22]

Within DoD, however, the pendulum had clearly swung back to a narrowly defined role for DoD in the nation's industrial and technology base. The focus of research and development was on Defense-specific technologies, and DoD's role in broader issues of industrial competitiveness was minimized. Yet many of the underlying concerns that motivated the Costello initiative continued to be raised by a number of panels, commissions, and boards. In addition, Congress actively promulgated legislation that focused on critical technologies and infused the Defense budget with technology development and support programs that were clearly dual-use in nature and not requested by the Bush White House.[23]

To further complicate the issue, the collapse of the Soviet Union as a threat brought into question some basic priorities of DoD's R&D programs. These programs had been optimized for the development and fielding of highly advanced new systems to technologically "outflank" the Soviet Union, but they had also been meant for important "spin-off" and "infrastructure" roles in the larger economy. The end of the Cold War raised the specter of drastic budget reductions for high technology weapon systems and their supporting programs. Some argued that the end of the Cold War would provide a "defense dividend" that could be invested in direct support of commercial technologies to promote so-called national competitiveness and to meet the challenge to continued U.S. world technology leadership posed by Japan and Europe. The stage was set for a debate over the proper role of government vice industry and economic security.

C. THE ORIGINS OF THE TRP: "ITS THE ECONOMY, STUPID"

From the outset, both the Democratic Congress and the Clinton administration had decidedly economic aims for the TRP, and the pursuit of dual-use technologies to

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22 Department of Defense 1989, 12.

23 See *Defense Critical Technology Plan* and the *Program Information Package* for TRP.

provide significant benefits to defense in many ways was a secondary consideration.[24] The program originated from a confluence of above described trends in U.S. public policy thinking. On the one hand, in the late 1980s and early 1990s it appeared that U.S. commercial competitiveness was severely eroding. This was evidenced by a rising foreign share of U.S. markets and declining U.S. share of foreign markets, increasing foreign technological sophistication and manufacturing capabilities, and a general decline in the rate of growth of U.S. productivity heralding a concomitant erosion of U.S. real wage levels. On the other hand, even with the end of the Cold War there appeared to be a clear need to maintain strong commitments to national security to support the new "internationalist" role of the U.S. on the world stage. The challenge was to do this in the face of declining defense budgets, increasing proliferation of high technology weapons from foreign sources (allies and adversaries, alike), and enduring inefficiencies in the acquisition system.

When the Clinton administration entered the White House in 1993, one of its first acts was to release a new technology policy document, *Technology for America's Economic Growth, A New Direction to Build Economic Strength*, which enunciated the pursuit of three goals: 1) "long-term economic growth that creates jobs and protects the environment;" 2) "a government that is more productive and more responsive to the needs of its citizens;" and, 3) "world leadership in basic science, mathematics, and engineering."[25] This document recognized the de facto technology policy that had existed since World War II through defense expenditures, and called for increased reliance on commercial industry to meet the needs of the military, including a call for increased reliance on dual-use:

> The nation urgently needs improved strategies for government/industry cooperation in the support of industrial technology. These new approaches need not jeopardize agency missions: In many technology areas, missions of the agencies coincide with commercial interests or can be accomplished better through close cooperation with industry. . .

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24 The original eight statutes for the TRP combined programs intended for DoD execution with those intended for the National Science Foundation and the National Institutes of Standards and Technology. The funding for the execution of these programs was lumped together in the 1993 Defense Authorization and Appropriations Acts due to the then existing Gramm-Rudman budget agreement which limited non-defense discretionary spending.

25 Clinton and Gore 1993, 3.

> A significant portion of DoD's research and development budget is already focused on dual-use projects—particularly projects supported by the Defense Advanced Research Projects Agency (DARPA). Since a growing number of defense needs can be met most efficiently by commercial products and technology in the years ahead, this fraction will increase. DoD is developing a strategy to improve the integration of defense and commercial technology development.[26]

In fact, the administration's use of the TRP was clearly part of its overarching goal to increase the level of long-term public sector investments in technology, education, and manufacturing. The execution of the program's eight statutes as a single, competitive package, spanning technology development, technology deployment, and manufacturing education and training, also fit well with the goal of reinventing government. The sizable first year TRP appropriation of almost $500 million was politically opportune and seen as a palliative for communities affected by the onrush of base closures and so-called defense conversion initiatives undertaken by the administration in its first few months in office.

It is important, however, to understand the origin of the strategy for the use of DoD monies for activities intended to benefit both the commercial and defense sectors. Authorizing legislation for the TRP, contained in 10 U.S.C. § 2501, explicitly included references to economic benefits that were to result from this government funding. The language, penned by Democrats in the Congress during the Bush administration, clearly evidenced an intent to bias the program toward applications spanning military utility and commercial viability (see Appendix A for a full text of 10 U.S.C. § 2501). This overarching language covered all of the TRP statutory programs that were authorized under the Defense Conversion, Reinvestment, and Transition Assistance Act of 1992.[27]

Since the first round of the TRP, in which 212 projects were selected, the original mission of the program as conceived by the Clinton administration has been revised considerably. The most fundamental of these revisions resulted from the election of a Republican majority in both the House and Senate in 1994. Since that time the administration has effectively "inverted" its emphasis on economic and commercial relevance, and played-up the military relevance of TRP projects. Compare the original statement by President Clinton announcing the TRP at Westinghouse in Baltimore,

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26 Note that this "strategy" significantly involved the Technology Reinvestment Project. Clinton and Gore 1993, 7–8.

27 Division D of the National Defense Authorization Act for FY 1993 (P.L. 102-484).

Maryland, with his subsequent statement announcing the first round of TRP awards on 22 October 1993, and the statement by Vice President Gore defending the TRP from Hill Republicans on 8 September 1995.

> **President Clinton, 11 March 1993:** "Starting now, this agency, ARPA, will allocate more than $500 million to technology and industrial programs, like the ones we've seen here today. We'll support industry-led consortia and dual-use technologies, and promote efforts to break through with commercial uses of formerly defense technologies."[28]

> **President Clinton, 22 October 1993:** "When I started running for President, one of the core ideas that animated my campaign and that got me really committed to the long endeavor of 1992 was the commitment that we had to find a way as we built down defenses to build up a new economy for America with new partnerships between defense technologies and the commercial future that we all seek for our country."[29]

> **Vice President Gore, 8 September 1995:** "I am disappointed that the House of Representatives voted Thursday to end the Defense Department's Technology Reinvestment Project, the flagship program in our effort to use cutting-edge commercial technology to maintain our military advantage."[30]

This revised theme, that the primary objective of the TRP is to support defense through commercial spin-on rather than to support commercial endeavors through spin-off, has been amplified through a host of administration publications. The content of these documents is summed up by what the Clinton administration calls the three pillars of dual-use technology policy:

Pillar 1: Bolster Leading-Edge Dual-Use R&D

Pillar 2: Integrate Commercial and Military Production to Enable Industry to Dual Produce

Pillar 3: Insert Commercial Products and Capabilities into Defense Systems[31]

As noted in Chapter 2, it is difficult to foresee the future of the TRP under a Republican Congress. Even though there is common ground between Democrats and

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[28] Executive Office of the President 1993a.

[29] Executive Office of the President 1993b.

[30] Executive Office of the President 1995.

[31] National Economic Council, National Security Council, and Office of Science and Technology Policy 1995, 15, 19, and 25, respectively.

Republicans on the Hill regarding the need for increased affordability and the benefits accruing from greater reliance on commercial industry to meet the needs of the military, the identification of the program with the Clinton administration makes it a "hard sell" in the current, ideologically charged political environment.

D. IMPLICATIONS FOR DUAL-USE PROGRAMS

Clearly, the use of government funds to pursue projects that may prove beneficial to both the commercial and military sectors has historical precedence. Nonetheless, the extent to which commercial considerations should be allowed to modify or change the orientation and mission of DoD investments remains an ideologically charged issue. Most politically contentious are likely to be dual-use programs targeted primarily toward industrial base strengthening, the overarching themes of which are economic growth, jobs, and competitiveness. Purposeful spin-off is also subject to challenge, particularly when it is viewed as a palliative to communities affected by defense budget reductions or as a means to promote defense conversion. Direct and indirect spin-on are likely to be less contentious so long as specific military missions are pursued.

This is not to say, however, that a given approach to promoting dual-use should be discounted because of the political ideology it reflects. Indeed, recent technology policy demonstrates that both Democrats and Republicans recognize the need to increase the military's reliance on the commercial industrial base. The fate of dual-use programs is, however, affected by a broader debate over the "proper role of government," wherein investment in a dual-use program that has clear military objectives may be questioned. Thus, regardless of the model a dual-use program embodies, its acceptance requires a broad, bi-partisan consensus on the goals and objectives being pursued, and clear demonstration that the means chosen are best suited for the task.

E. SUMMARY

- Prior to World War II, and in particular prior to the Great Depression, intervention by the U.S. government in economic affairs could best be described as "infrastructural." During the Cold War, the United States pursued a de facto industrial policy through the Department of Defense, using research, development, and procurement expenditures for both national security and economic purposes.
- Despite massive public sector funding levels for R&D in the United States since World War II, the nation's significant scientific and technological lead over other countries eroded in the decades of the Cold War. Findings of the

National Academies of Science and Engineering, and of various economic competitiveness studies, appeared in the 1980s following mounting concerns regarding "declining industries" and slowing productivity growth rates earlier in the decade.

- In response to competitiveness concerns, the Bush administration issued the first ever explicit U.S. Technology Policy, which called for investments in pre-competitive and generic research and development. Commissions and private organizations called for increased attention to dual-use, monitoring of foreign technology developments, and expansion of DARPA's role to a national scale through the creation of a National Advanced Research Projects Agency.

- For DoD, dual-use programs are a means to implement its post-Cold War strategy of taking advantage of the most advanced commercially available technologies while also making weapon systems more affordable by relying on cutting-edge commercial technologies. When viewed from this vantage point, the success of dual-use policies and programs becomes virtually inseparable from overall acquisition reform issues. Indeed, acquisition reform must be addressed as a significant factor in the potential structure and success of any dual-use effort.

- During the 1980s a variety of reports and studies offered recommendations for reforming the DoD acquisition system, increased military reliance on commercial capabilities, and warning of an erosion in the U.S. technological lead vice its allies and adversaries in critical component areas.

- When the Clinton administration entered office there was a renewed emphasis on technology as both key to military superiority as well as central to improved national economic performance. Three primary goals were to be pursued: 1) long-term economic growth that creates jobs and protects the environment; 2) a government that is more productive and more responsive to the needs of its citizens; and, 3) world leadership in basic science, mathematics, and engineering.

- Since the first round of the TRP, in which 212 projects were selected, the original mission of the program as conceived by the Clinton administration has been revised considerably. The most fundamental of these revisions resulted from the election of a Republican majority in both the House and Senate in 1994. Since that time the administration has effectively "inverted" its emphasis on economic and commercial relevance, and played-up the military relevance of TRP projects.

- Through efforts such as the Technology Reinvestment Project, the Clinton administration actively and openly pursued dual-use as part of a three-pillar strategy:

Pillar 1: Bolster Leading-Edge Dual-Use R&D

Pillar 2: Integrate Commercial and Military Production to Enable Industry to Dual Produce

Pillar 3: Insert Commercial Products and Capabilities into Defense Systems

- Clearly, the use of government funds to pursue projects which may prove beneficial to both the commercial and military sectors has historical precedence. Nonetheless, the extent to which commercial considerations should be allowed to modify or change the orientation and mission of DoD investments remains an ideologically charged issue. Simply because one or another approach to promoting dual-use has one or another type of ideological baggage attached to it, however, does not mean that it should be removed from future consideration. Despite the dual-use model employed, to find acceptance there is therefore a need to develop a broad, bi-partisan consensus on the goals and objectives being pursued, and clear demonstration that the means chosen are best suited for the task.

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IV. HISTORICAL EXAMPLES OF DUAL-USE IN THE UNITED STATES

Recent commotion about the use of commercial technologies for military purposes, and the commercial benefits from defense investments, ignores the fact that, until the post-World War II period in the United States, commonality across these sectors was more the rule than exception. Indeed, technological advances have historically flowed between the two sectors. This chapter looks at applications of dual-use technology developments from the interwar period (1918 to 1939) and at private sector consortia and government-industry partnerships as models for collaborative dual-use technology development.

In the first section we focus on the interwar period rather than on more modern examples of dual-use for two reasons: 1) more modern examples, such as the Boeing 707, Global Positioning Satellites (GPS), Internet, super/parallel computing, microelectronics, and so forth, are well documented elsewhere;[1] 2) these dual-use capabilities were developed during the Cold War when military funding was bountiful, while the interwar period was a time of severely constrained budgets much like the current post-Cold War experience. In the second section we explore four examples of private sector consortia and government-industry partnerships; such collaborative enterprises are key in dual-use programs such as the TRP, which encourages the formation of alliances for R&D purposes.[2] However, because most TRP projects are relatively young, and because this paper is intended to assist the deliberations over a follow-on dual-use program to the TRP, we examine activities outside that program, including a consortium that had no government impetus (MCC) but nevertheless participates in government research.

At the end of each section we offer observations on the degree to which the subject dual-use activities proved successful, and tie our findings back to the four dual-use program models advanced in Chapter 2.

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1 See Alic et al. 1992.

2 We assume that most readers of this paper are knowledgeable about the TRP and that a review of these programs is unnecessary. Readers who want such a review and discussion of possible future directions for technology policy should see Stowsky and White September 1995.

A. EXAMPLES FROM THE INTERWAR PERIOD

The historical antecedents to the current effort to encourage dual-use date back to the period between the end of World War I and the eve of World War II, a period during which the defense research and development environment was similar in many respects to today's. The years between 1918 and 1939 were the last extended period of military planning absent a major, strategic threat from the Soviet Union. Americans were confident of their near-term strategic security; and while they recognized the possibility that Germany and Japan were potential threats, Americans generally felt that threat was distant. Like their counterparts in the 1990s, political leaders in the 1920s felt considerable pressure from a war-weary and increasingly isolationist public to reduce spending on defense and free resources for economic growth. By the 1930s, the sense of strategic security was dwindling, but economic depression made the allocation of significant resources for military modernization impossible.

The imbalance between the ambitions of national strategy and the political willingness to pay for it has been a perennial problem for U.S. military planners, even during the Cold War era. During the interwar years, especially the 1930s, the military leadership—again, similar to their modern counterparts—found themselves constantly warning that the military did not have the material and human resources to deliver on the promises to which national strategy committed it. Military budgets and manpower levels between 1920 and 1936 were woefully small and allowed virtually no margin for doctrinal development or technological research and development. Both the Navy and the Marine Corps, moreover, maintained a brisk if low-level pace of operational activity throughout the period that constituted a further drain on scarce resources. The military establishment of the mid-1930s felt no better able to challenge Japan in the Pacific and Germany in Europe than military leaders today feel able to conduct numerous small contingency operations while maintaining readiness for two Major Regional Contingencies.[3]

Just as the military today faces the challenge of incorporating radical new technologies into its existing capabilities, the military of the 1920s and 1930s grappled with the implications of their own military-technical revolution. The late-19th and early-20th centuries saw dramatic technological advancement in both the private sector and the military that bore potentially revolutionary implications for the business of warfare. Electrification, radio technology, aviation, internal combustion engines, and submarines

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3 Ziemke 1991, 61–76.

all had to be merged into the mainstream of military operations. The advent of these new technologies created new challenges and responsibilities for the armed services and spurred often heated debate over their implications for military doctrine and modernization both within the services and between the military and civilian political leaders. The challenges were considerable as new organizational structures, doctrines, training, and equipment had to be incorporated into existing force structure and concepts of warfighting. In the two decades following the end of World War I, the United States developed three air forces (the land-based Army Air Corps, the Navy's carrier aviation fleet, and the Marine Corps' air-ground support air arm); a mechanized, armored Army; a submarine fleet; an amphibious force; and entirely new concepts of warfighting to accommodate them.

Few of these advances would have been possible without the close cooperation of military and civilian researchers. Here lies yet another common thread that ties the interwar experience to the military planning environment of the 1990s: the common interest that the military and certain sectors of civilian industry shared in the advancement of new technologies with expensive and potentially high risk research and development demands. In many cases, the military services were able to forge alliances and partnerships with private industry that served their common, long-term interests. These relationships were seldom as formal, or as complex as what today would be recognized as a dual-use policy; nonetheless, they provide some useful lessons concerning the benefits of cooperation between the defense and civilian research and development establishments. This section presents brief surveys of this military/government-civilian cooperation as it functioned in four cases: the Navy's development of radar and its application to civilian aviation after World War II, the Army Air Corps' program to develop long-range strategic bombers, the Marine Corps' search for amphibious vehicles, and the U.S./British push to accelerate the development and production of penicillin.

1. Radar

The history of the development of radar in the United States is an interesting case study as much for its negative lessons as for its positive ones. For historians of military research and development this case is interesting because of its complexity. In an international context, this case is interesting because it provides an example of parallel technological development—Great Britain, the United States, and Germany all devoted resources to developing radar detection capabilities. From the perspective of dual-use, the case includes elements of each of the four models for promoting dual-use: direct and indirect spin-on, purposeful spin-off, and industrial base strengthening.

The development of radar was concentrated in two parallel but unconnected efforts in the U.S. Naval Research Laboratory and the Army Signal Corps. Prior to the First World War, the United States Navy had developed and maintained a very strong working relationship with engineers and entrepreneurs in the private sector. Companies like General Electric, American Telephone and Telegraph, and the Radio Corporation of America had learned that scientific research that pressed the advancement of technological knowledge could also dramatically improve their market share. The Navy was willing to piggyback its technological development on those private sector efforts while industry benefited from the dramatic naval build-up, particularly the conversion of the U.S. fleet from sail to steam and from coal to oil over the first two decades of the century.[4]

Beginning during World War I the Navy moved away from the Industrial Research model toward the development of its own internal scientific research and engineering establishment. After a few false starts, it launched the Naval Research Laboratory, which commenced operations in 1923, the cornerstone of an R&D juggernaut that included the special scientific research group at New London, Connecticut; the Naval maritime engineering post-graduate school at Annapolis; and the Navy's maritime architectural program at MIT. In principle, the NRL was intended to make the Navy a patron of science that brought together the best of academic scientific research, industry's technical know-how, and military expertise. In practice, the NRL quickly fell out with its civilian advisors over procedural and organizational differences and became isolated, and the once robust relationship between the Navy and industry languished.

The government's first push for the development of radio detection devices came after the *USS Titanic* disaster, but the real commitment to radar research came in 1917 in the wake of Germany's unrestricted submarine warfare. The scientists at New London were charged with solving the submarine detection problem, while the challenge of applying new technology to the detection and location of enemy vessels on the surface fell to the NRL. The earliest technical breakthroughs came in 1922, when navy engineers first demonstrated that radio waves could be employed to detect the presence of objects at a distance. By the early 1930s, the NRL had made sufficient progress to conclude that

4 McBride 1992, 8–9; Allison 1981, 1–38.

radar had significant potential operational utility as a means to detect the presence of enemy vessels and aircraft.

At the same time that the Navy was conducting radar research at the NRL, the U.S. Army Signal Corps Laboratory was exploring the potential of radio detection. The Royal Air Force had begun research into the application of radio technology to the detection of incoming enemy aircraft; the RAF work triggered the U.S. Army's interest once early indications that the idea had some technological promise. The Army was similarly interested in radio's potential as a tool for air defense, artillery targeting, and long-range battlefield communication. Its efforts, however, were hampered by a lack of funding and declining industry interest in radar-related technologies. The Army was dependent on industry for most of its sophisticated scientific research projects because its Signal Corps Laboratory was configured for applying outside technological advancement to the practical development of military equipment, not to the conduct of original and independent research.

By the late 1930s, the Navy and the Army had made significant progress on radar, but they did so independently and with much duplication of effort. It was not until the creation of the National Defense Research Committee (which later became the Office of Scientific Research and Development, OSRD) in 1940 that the development of radar for military use saw real cooperation and coordination of effort among the Navy and Army laboratories, academic scientists, government, and private industry. From that point on, advances in radar technology accelerated dramatically. Considering that the first operational tests on U.S. naval vessels only occurred in 1939, the extensive use of air-defense and targeting radar by all the services in World War II is little short of extraordinary. While it is true that the United States was further advanced than any other country in radar technology by the eve of the war, it is also true that had government coordination of Army and Navy efforts begun sooner, the U.S. armed forces could have entered the war with a potentially insurmountable technological advantage.[5]

Despite the self-contained nature of military radar development, the new technology had a fairly robust history in the civilian sector that contributed indirectly to the military effort and directly to the application of radar in the post-war civilian sector. The earliest technological breakthroughs that allowed the development of radar were the direct result of the electrification of the Pacific Coast. Southern California Edison, Cal

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5 Spector 1988, 75–76.

Tech, Pacific Gas and Electric, and Stanford University were all conducting scientific research to solve the problem of how to transmit very high electric voltage over the long-distances between hydroelectric plants and coastal cities. The klystron technology that proved key in the advancement of radar research was a spin-on of that research, as were microwaves and X-ray technology for industrial and medical application.

The most significant spin-off of military radar research into the civilian sector developed after World War II with the creation of the worldwide network of air-traffic control systems. Wartime research into the development of IFF (Identification, Friend-or-Foe) radar systems for use in air-defense systems did not develop a usable military system before war's end, but the technological advances it made paved the way for air traffic radar. The military research establishments in the U.S. and Britain had dropped the IFF effort after 1945, but the Berlin crisis of 1949 and the resulting massive allied airlift created a demand for air traffic radar and resulted in the eventual development of the current civil aviation system. The first civil air traffic control radar system was tested at London's Heathrow Airport in 1952, and the rest is history. Today's ever-expanding passenger and freight aviation system could not have developed without the relatively early development of an advanced civil aviation control system. Private industry, however, could not have borne the start-up cost of developing the appropriate technology had there not been a significant government investment up front in the form of military research and development.[6]

2. Amphibious Landing Craft

The United States Marine Corps tied its institutional development during the interwar years directly to its evolving doctrine and capabilities for amphibious warfare, which the Marines believed would be potentially decisive in any future war in the Pacific. The Marine Corps published its first complete amphibious doctrine manual by 1934, but fiscal shortages limited testing, training, and the development of appropriate hardware until the late 1930s. On the eve of World War II the Marines still lacked one key category of equipment: landing craft suitable to transport personnel and supplies quickly across the wide beaches and treacherous coral reefs of the Southern Pacific in the course of an amphibious assault on a defended position. The Marine Corps search for appropriate landing craft began in 1934 but was hampered by fiscal shortages and institutional

6 Trim 1994, 93–120.

indifference from the Navy's Bureau of Ships and Bureau of Construction and Repair. The Navy's existing Landing Ships Boats were deemed grossly inadequate as a result of operational exercises conducted in 1938 and 1939. Amphibious vehicles were not a high priority item for a navy engrossed in building carrier air and submarine fleets. In its typical take-charge style, the Marine Corps established an Equipment Board at Quantico and charged it with conducting an exhaustive search and lobbying effort to secure better landing craft.

The Marine Corps Equipment Board scoured the country for applicable off-the-shelf capabilities and found the solutions to their problem in the workshops of two civilian engineer/entrepreneurs.[7] In 1924 Andrew Higgins, a New Orleans entrepreneur, had designed a powerful, 30-foot, shallow draft boat with a reinforced underwater hull that protected the propeller from hitting bottom in shallow waters. The Higgins Boat, which he called the "Eureka," was originally designed for use by Prohibition era rum-runners operating in the Mississippi Delta. Higgins first offered his design to the Navy in 1926, but they were not interested. The Marines first saw the Eureka in 1934 and immediately forged a working partnership with Higgins that resulted in the first prototype of a Marine Corps landing craft in 1937. Operational tests in 1938 were promising, and the Marines gave Higgins additional money to perfect his prototype by expanding its length, enlarging its troop compartment, and modifying its engine. The final adjustment was the design of a retractable bow ramp, which the Marines modified based on drawings of a Japanese landing craft. The end result of this exercise in civil-military cooperation in research and development was the Navy's Landing Craft Vehicle, Personnel (LCVP), the workhorse of Marine Corps amphibious operations well into the 1970s.

The Higgins Boat did not solve all of the Marine Corps' amphibian problems. Higgins had designed a Landing Craft, Mechanized (LCM), capable of delivering an army tank to shore, but the Marines remained interested in developing an amphibian tank that could bring heavy fire power to bear in the early stages of an assault on a hostile beachhead. In 1937, the Equipment Board became aware of another civilian engineer, Donald Roebling, who had developed an amphibian tractor for use in search and rescue missions in the Everglades. Like the Higgins Boat, the Roebling "Alligator" required significant modification before it proved suitable for Marine Corps' adaptation. The Marines worked closely with Roebling in developing the amphibian tank, and by

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7 This section is based on accounts provided in Krulak 1991, 339–342.

September 1940 had received delivery of the first prototype. The Landing Vehicle, Tracked (LVT), was in full production by July 1941 and the first battalion of LVTs landed at Guadalcanal in August 1942. The significance of this success story goes far beyond Marine Corps operations in the Southern Pacific. The Marine Corps' versions of the Higgins Boat and the Roebling Alligator were the only feasible amphibian designs in the U.S. inventory and were eventually employed by the U.S. and allied armies in the Normandy landings.

The development of these Marine Corps amphibian vehicles is one of the great historical success stories of direct spin-on dual-use procurement. The Marine Corps had a very specific problem it needed to solve, it knew exactly what kind of technological solution that problem required, and it set about purposefully seeking civilian technology that would meet the demand. In Roebling and Higgins, the Marines found civilian entrepreneurs with products that, while they did not meet all military specifications, provided a sound base for modification and procurement. The Marine Corps worked closely with these civilian engineers and managed to produce and deploy the amphibian vehicles, meeting an urgent military need in an amazingly short period of time.

3. Long-Range Bomber Aircraft

The development of the long-range bomber aircraft that were the backbone of air operations in World War II is an important case study of how the military and civilian sectors can cooperate to build an industrial base and technological capability that neither sector could manage alone. All of the Services were hobbled in their modernization efforts during the interwar years by the isolationist politics that dominated the budget process from the early 1920s well into the 1930s. The Navy Department, however, did not suffer nearly so much of a strain because of its economic role and its traditional position as the United States "first line of the defense." The Army had a much more difficult time justifying its modernization programs, especially those for offensive capabilities like armor. Thus, the U.S. army in World War II had the best artillery in the world (ibecause its development could be justified for coastal defense) and the worst tanks (in part, because no one feared a ground invasion from Canada or Mexico: there was no threat driving innovation either inside our outside the Army). The modernization of military aircraft for the Army Air Corps (later the U.S. Army Air Forces) was a mixed success. Air Corps modernization suffered from chronically low Army funding overall and the national policy of "arming solely for defense." Most combat aircraft types—fighter escorts, attack aircraft, and long-range bombers—were impossible to sell to

Congress as defensive weapons. The Air Corps managed to develop an excellent medium-bomber, the B-17, under the guise of coast defense, but an Army-Navy agreement limited the offshore range of Air Corps aircraft to 500 nautical miles and prevented the development of a truly long-range bomber.

The Air Corps did not settle, however, for a medium-range capability that did not meet the demands of its developing strategic bombing doctrine. Instead, it forged a close working relationship with the civilian aviation and allied industries in what turned out to be true symbiosis. Civilian industry recognized the long-term commercial potential of aviation, but the near-term market was hardly sufficient to support the development of an independent aviation industry. The only hope was the influx of government support, which came, in part, in the form of research and development funding from the Air Corps. The Air Corps received at least two major advantages—civilian industry could conduct research and development efforts that were far beyond the capabilities of the Army's rudimentary Laboratory system, and support for the fledgling aviation industry built the foundation of an awesome wartime industrial base.[8] In addition to the development of combat aircraft, the Army Air Corps supported industry in developing high performance fuels, lubricants, and synthetic materials used to produce, operate, and maintain the air fleet.

The Air Corps and the civilian aviation industry shared one particular interest: the development of larger aircraft that could carry bigger loads over longer distances. Douglas, Martin, and Boeing aircraft corporations were all interested in developing long-range aircraft for cargo and passenger transport, but none could bear the overhead cost of long lead-time research and development efforts. The Air Corps, on the other hand, was interested in research and development (and had at least limited financial resources to devote to it) but would not be in a position actually to purchase long-range bomber aircraft unless and until the nation recognized a national security threat. The Air Corps faced stubborn institutional resistance to its strategic bombing concepts in both the Army and the political establishment and could not engage in outright bomber development programs. It could, however, get away with supporting the development of longer range cargo aircraft types (although it had no intention of purchasing the resulting airframes for use as anything other than strategic bombers).

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8 Craven and Cate 1948, 17–71.

These complex institutional and political dynamics resulted in an extremely close and effective relationship between the Air Corps and civilian aviation industry that continued well into the post-war years. In the lean times of the 1930s, when political and fiscal constraints could have stalled the development of military aviation and economic collapse could have killed the civilian aviation industry in its infancy, the two joined forces to make surprising advances. This civil-Air Corps alliance led directly to numerous key technological breakthroughs: dramatic improvements in payload and lift-to-weight ratios; the development of all metal, and later of lighter weight aluminum airframes; the advent of the monoplane, and multi-engine aircraft. Civilian aircraft companies had developed and marketed cargo and passenger aircraft, including the workhorse of World War II—the DC-3/C-47, that were, with minor modifications to meet military specifications, adopted directly into the air fleet for use as cargo and transport aircraft. When Congress finally recognized that war might lay on the horizon and money finally became available for aircraft development and procurement, most of the key scientific and technical barriers to the development of longer range and higher performance combat aircraft were either solved or well on their way to being so. The Air Force's first true long-range bomber and the backbone of the strategic bombing campaign against Japan in 1944–45, the B-29, was already in the latter stages of development when the United States entered the war in 1941.[9]

The Army Air Corps' experience provides an excellent historical example of the industrial base strengthening model of dual-use policy. In this case, the military and private sector realized early that they shared a mutual interest and, by combining their resources, could achieve much more than either could manage independently. Moreover, both the military and private sectors stayed flexible and imaginative in forging their relationship so that they might best meet their common goal of establishing a robust civilian industial base in a difficult economic environment.

4. Penicillin

The development of penicillin during the early war years demonstrates clearly that diverse, and even conflicting, interests can be organized and given direction and momentum when the government takes an active role as a facilitator, and occasionally, as an enforcer. British scientists first recognized the antibiotic potential of penicillin in

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9 Millett and Maslowski 1985, 384–385.

1929 but by the late-1930s researchers still had not made substantial progress toward producing or marketing it as a bactericide. The pharmaceutical industries in Britain and the United States were reluctant to invest much capital in developing the drug because it was difficult to produce in economically feasible quantities, was tricky to process, had undergone incomplete clinical testing, and was likely to be synthesized reasonably soon once its therapeutic value was proven. It was not until war broke out in Europe in 1939 that British and American scientists could garner the government support and industry cooperation necessary to accelerate the development of the world's first widely available antibiotic.[10]

Most of the early clinical breakthroughs in the development of penicillin were made in Britain, but the reticence of the British pharmaceutical industry to enter a risky new area, coupled with the immense pressure of the German bombing campaign in 1941 and 1942, made it extremely unlikely that the British would be able to produce penicillin in anything more than the minimal quantities required to treat only the most severe battlefield casualties. As a result, the two leading British penicillin researchers, Howard Florey and Norman Heatly, traveled to the United States in the fall of 1941 to recruit support from American industry and researchers who were also working on the penicillin problem. Three major U.S. pharmaceutical companies expressed interest in penicillin development. More important for the overall cause, however, was the alliance forged between the British researchers and Dr. A. N. Richards, a University of Pennsylvania professor of pharmacology and the chairman of the Committee on Medical Research (CMR) of the wartime OSRD.

Richards, with the endorsement of the CMR, arranged a meeting in October that brought together Vannevar Bush (director of the OSRD), representatives of the CMR and the National Research Council (NRC), government representatives from the Department of Agriculture, and the research directors of four major pharmaceutical companies: Merck & Co., Squibb, Pfizer, and Lederle & Co. Richards made clear to all concerned the CMR's intense interest in seeing penicillin enter large-scale production as soon as possible in order to support the war effort. Eventually, the companies involved overcame some of their misgivings and agreed to keep the CMR informed in detail of their progress, while the Committee, in turn, pledged to keep each company's developments confidential except where the dissemination of data was in the best interest of the overall

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10 See Helfand et al. 1980, 31–56.

effort. Here lay the functional basis of the industry-government relationship: everyone agreed that national interest would override commercial interest. The CMR also agreed that the government would bear the cost of standardization and clinical testing. Throughout the effort to get penicillin in large-scale production, the relationship held through regular meetings and good faith efforts to exchange information on significant breakthroughs and problems.

Once the problem of producing natural penicillin was tackled, the CMR turned its attention to the problem of synthesis, while the War Production Board took over the task of facilitating widespread penicillin production. The WPB secured the participation of 175 companies and financed the construction of penicillin production facilities for six of those companies. By mid-1943, the industry was producing penicillin at levels sufficient to meet the needs of the military. By the spring of 1944, production had risen to the point where a Civilian Penicillin Distribution United of the WPB began allocating the drug for civilian use. Penicillin production went from (effectively) zero units in October 1941, to 425 million units in June 1943, and 646 billion units in June 1945.

5. Lessons of the Interwar Experience

The 1920s and 1930s were much simpler times in many respects, not the least of which was in the rudimentary nature of the military research, development, and procurement process. For this reason, hard parallels between the interwar experience and today's effort to force dual-use policies are difficult, if not impossible, to draw. It is important, in thinking about the utility of these historical case studies, to avoid the temptation to dismiss the experiences that emerge from the interwar years because the bureaucratic and accounting practices of that simpler era of government look so different. The interwar experience offers valuable insights into the advantages, disadvantages, benefits, and risks of direct collaboration among the government, the military, academe, and private industry in the advancement of new technology that bears the potential of great payoff for all the elements concerned.

The history of the development of radar demonstrates clearly the advantages of inter-Service, and civilian and military cooperation by the fact that, in this case, it did not happen. The United States made impressive advances in radar technology by the eve of World War II, but its technological advantage in this area could have been insurmountable—in, for example, the development of a wartime IFF capability—had true cooperation taken place from the beginning of the research and development effort. The development of radar was initiated at a time when the Navy was moving away from its earlier practice of close cooperation with, indeed principal reliance on, industrial research and development—direct and indirect spin-on. Private industry largely removed itself from the radar effort until the late 1930s because the Navy made no effort to convince it that there was mutual benefit to be gained from cooperation. In reality, the private sector made some important contributions to the development of radar, but those contributions came to the Navy slowly and through the "back door" because there was no central agent keeping track of relevant work and making an effort to coordinate government, military, and industry efforts.

In contrast, the story of penicillin production constitutes a dramatic success story that makes essentially the same case: that centralization of effort can bring huge payoffs in time and level of success, and does not need to threaten the incentives of private industry. It is not clear that the large-scale production of penicillin would have happened at all without the intervention of a close government-industry alliance—an example of indirect spin-on. In any case, penicillin production would have stayed on a very low level throughout the war, providing little more than the minimum necessary to treat only the most severe wartime injuries. To be sure, antibiotics would eventually have been synthesized, but that process would have taken years longer and, given the difficulty in large-scale production, would likely have skipped the stage of natural penicillin production altogether. No single player in this story—the British or American researchers, the pharmaceutical industry, or the government—could have produced the miracle of penicillin on its own. It took a centralized intelligence with a strong will, access to incentives, and the ability to put pressure on the system (in this case, the appeal to the patriotism of the pharmaceutical industry) to make the miracle happen.

The amphibian vehicle example suggests a similar lesson: that cooperation can provide benefit to both the military and the civilian industry involved—in this case through direct spin-on. Both Roebling and Higgins had inventions with limited economic promise in the civilian sector. The Marine Corps had a very specific technical problem upon which its entire operational concept hinged, but it did not have the institutional means to develop the necessary capabilities in-house. Fortune brought the Marines, Higgins, and Roebling together, but common sense and close cooperation, unhindered by overregulation and overspecification, provided a solution to all their problems.

Finally, the experience of radar and long-range bomber development show that the short-term investment in cooperative research and development can bring enormous long-term dividends that cannot even be foreseen at the time—a case involving direct and indirect spin-on, purposeful spin-offs, and ultimately industrial base strengthening. The civilian aviation and air travel/transport industries that constitute such an important part of the modern world economy would have been impossible without the technological advances made as a result of military research and development of radar and long-range aircraft. The massive scale of air traffic that criss-crosses the modern world would be impossible without the sophisticated and complex air traffic control system that was first built on the IFF technology that resulted from the wartime search for combat IFF capabilities, and the effort to manage the Berlin Airlift of 1949. Likewise, the limited resources that the Army Air Corps pumped into the infant aviation industry during the 1920s and 1930s nurtured that industry through its early stages of steep learning curves, small markets, and marginal economic payoffs. Again, while it is certainly true that these industries would eventually have developed without military incentives and government intercessions, they would have done so more slowly and, in all likelihood, less efficiently.

B. THE ROLE OF R&D CONSORTIA AND TECHNOLOGY POLICY

Central to the debate on dual-use and the industrial base is the question, How can the federal government best pursue technology goals that it believes are critical to national well-being? In this section we briefly review and assess the experiences of four efforts that are intended to advance the state of the art in applied technology areas believed to be in the immediate interest of U.S. industry and the nation.[11] While only three of the four efforts are explicitly government sponsored, all share a common vision using shared R&D resources to accomplish technical objectives critical to national security and economic prosperity.

The oldest of the programs, VHSIC, began at the end of the Carter administration as a military R&D program to attempt to reintegrate the increasingly divergent interests of the commercial and defense microelectronics industrial bases. It exemplifies both indirect spin-on and purposeful spin-off. The Microelectronics and Computer Corporation (MCC), a privately funded R&D consortium that was founded by industry and which has received some ARPA funding, was started to meet the perceived foreign (Japanese) threat to American preeminence in the computer industry. We include it as an example of the type of collaborative R&D activities that may arise without government

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[11] Three of the efforts are still ongoing.

involvement, but suggest that such alliances may be useful vehicles for pursuing dual-use goals. SEMATECH, another R&D consortium, was established to reassert U.S. leadership in the semiconductor industry and has become a well-known, if not controversial, archetype for industrial base strengthening through government funding for strategic national industries.[12] Finally, IHPTET was conceived as a military R&D program whose purpose would be to make substantial advances in the performance of turbine engines, a critical component in major weapons platforms in all three Services and we view it as representing purposeful spin-off.

To facilitate evaluating the four programs we organize them in terms of two underlying characteristics: focus and mechanism. By "focus" we mean whether the program's goals/directions were principally commercial or military. While there is certainly a continuum between these extremes, we characterize dual-use program as one somewhere in the middle, and all four of the programs we survey here lean heavily in one direction or the other. Two, MCC and SEMATECH, are effectively driven by commercial needs, while VHSIC and IHPTET are driven by military requirements. By "mechanism" we mean whether the R&D programs have been implemented by pooling resources, as in a typical research consortium, or via the traditional DoD approach of awarding individual R&D contracts with competition between vendors or teams of vendors. MCC and SEMATECH operate like true research consortia, while VHSIC and IHPTET use a more "acquisition like" approach.

1. SEMATECH

The original impetus for SEMATECH was the loss of U.S. leadership in semiconductor manufacturing. By 1987, the U.S. share of world semiconductor production had fallen from 50 percent at the start of the decade to under 40 percent. The most publicized aspect of this issue was the dominance of Japanese firms in the production of RAM chips. Less well known but of far greater consequence was the decline in the domestic production of manufacturing equipment. From the perspective of U.S. semiconductor manufacturers, given the nature of Japanese industrial structure and policy, this change might have eventually led to a decline in competitiveness in all areas of semiconductor manufacturing. The Defense Science Board Task Force on Semiconductor Dependency in 1989 concluded that U.S. technology leadership in

12 Unlike MCC, SEMATECH received direct federal support through ARPA until just recently. These expenditures were justified by the potential loss of an industry critical to national security.

semiconductor manufacturing was rapidly eroding and that this had serious implications for the nation's economy and immediate and predictable consequences for the Defense Department. From the DSB's perspective, the loss of domestic leadership in such a critical area in the development and production of military equipment posed an unacceptable risk to national security.

Of the original 12 semiconductor manufacturers who formed SEMATECH, two have withdrawn since its founding in 1987. The current membership consists of AMD, AT&T, DEC, HP, Intel, IBM, Motorola, National Semiconductor, Rockwell, and Texas Instruments. The following list, taken from *SEMATECH, 1994 Accomplishments*, are the consortium's stated corporate objectives:

- Provide member companies with the lowest cost production of leadership semiconductor products. Reduce or eliminate the rate at which capital costs per unit output increases as product complexity.
- Ensure access to a competitive supplier infrastructure capable of meeting the member company requirements for selected key equipment materials, models, simulation tools, and manufacturing systems.
- Provide cost-effective, flexible factory capabilities that can deliver wafers to suppliers for their equipment development.
- Provide solutions to the semiconductor industry for Environment, Safety, and Health conscious manufacturing.
- Provide member companies with at least 3X Return on Investment.
- Champion the National Technology Roadmap for Semiconductors and work with the government to implement timely improvements in semiconductor technology. Cooperate with all organizations involved in semiconductor R&D to develop a research and educational infrastructure necessary to sustain US leadership in semiconductor technology.
- Maintain open forums for effective communication, collaboration, and consensus-building within the SEMATECH community.

To accomplish its goal of restoring the competitiveness of domestic semiconductor manufacturing technology, SEMATECH focuses on short-term, evolutionary improvements.[13] One central tenet of its operation has been attention to key generic processes and core equipment critical to maintaining a world-class manufacturing

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[13] Eighty percent of SEMATECH's funding is directed at improvements that had a time horizon of 1.5 to 3 years between start of R&D and deployment.

capability. With this emphasis on strengthening upstream suppliers, SEMATECH has minimized conflicts between its member companies since merchant chip firms do not compete on end products (e.g., computers).

SEMATECH's current budget is $180 million per year, up from $100 million at its founding in 1987. Since the consortium's inception its funding has been split evenly between ARPA and member contributions. The full privatization of SEMATECH was planned to have taken place at the end of the first 5 years of its operation. However, the consortium was able to secure continued federal support for an additional 5 years,[14] beyond which time it will be supported entirely by private funds.

To achieve its goals, SEMATECH divides its research program into 15 areas, or thrusts, as follows:

- Interconnect
- Materials and Bulk Processes
- Lithography
- Contamination-Free Manufacturing
- Manufacturing Systems Development
- Modeling and Statistical Methods
- Environment, Safety, and Health
- Test and Electrical Characterization
- Manufacturing Methods
- Planning and Technology Transfer
- Total Quality
- Design
- Assembly and Packaging
- Critical Materials
- Future Factory Design

These represent a somewhat broader set of issues and challenges than the originally conceived R&D agenda, which concentrated on wafer fabrication to reach and maintain parity with foreign (principally Japanese) suppliers. As may be inferred from the list, today the scope is broader and encompasses areas that will ensure an American advantage in semiconductor manufacturing technology in general.[15]

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14 Recent legislation terminates federal government funding for SEMATECH in 1996, one year earlier than originally planned by the 5-year extension.

15 Unlike catching up, gaining advantage is by definition a more complicated, and perhaps, more speculative, objective.

Within the U.S. segment of the global semiconductor industry over the past several years, positive trends have emerged since the start of the consortium. The U.S. share of semiconductor manufacturing has risen dramatically, and a growing proportion of equipment in new semiconductor manufacturing facilities is manufactured domestically. SEMATECH also appears to have been instrumental in helping establish long-term relationships between member companies and their suppliers which, in turn, have speeded up the deployment of new manufacturing technologies.

These gains notwithstanding, critics of SEMATECH contend that the consortium may have been incidental to the revival of the semiconductor industry. They say that the real reason for improvements lay in U.S. industry's competitive advantage in the design of specialized integrated circuits. In retrospect, Japan's semiconductor manufacturer's emphasis on memory chips has made them vulnerable to competition from Korean and Taiwanese competitors in what has become a commodity market with very low margins. Another issue has been that a number of smaller semiconductor firms were effectively precluded from participating in SEMATECH because of the cost of membership, and consequently were not able to benefit (at least immediately) from a government subsidized program.[16]

2. Integrated High Performance Turbine Engine Technology (IHPTET)

IHPTET began in 1988 as an inter-Service program to develop turbine engine technologies capable of delivering double the propulsion performance of current systems by the year 2000. The plan to reach this goal is slated to be implemented in three stages, successively achieving 30 percent, 60 percent, and 100 percent, of the ultimate performance target. IHPTET includes the Army, Navy, Air Force, NASA, ARPA, and six industry participants: Allison, Williams International, Teledyne Ryan, Allied Signal, General Electric, and Pratt & Witney. At the end of each stage of the program, improvements are expected to be immediately applicable to existing aircraft and missile engine designs. Through the development of advanced materials and structural designs, goals include improved durability and reduced maintenance costs.

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[16] The distortions can arise in two ways. First, if the technical concerns of large companies were different from those of smaller ones, SEMATECH could well bias its research agenda in favor of its members, whereas equity and efficiency would lead to a broader focus, at least with respect to the taxpayers' portion of the funding. Second, SEMATECH could enhance the competitive advantage of its members relative to non-SEMATECH members by restricting the sales of advanced equipment from the recipients of SEMATECH grants.

IHPTET's R&D programs are implemented through technology demonstration projects awarded to industry for three classes of gas turbine engines addressed by the program: *turbojets/turbofans* for fixed wing aircraft, *expendables* for missiles and rockets, and *turboshafts/turboprops* for helicopters. For turbojets/turbofans, the core technology demonstrator programs are the Advanced Turbine Engine Gas Generator (ATEGG) and the Joint Technology Demonstrator Engine (JTDE); for expendable turbojets/turbofans, the Joint Expendable Turbine Engine Concept (JETEC); and for turboshafts/turboprops, the Joint Turbine Advanced Gas Generator (JTAGG).

What distinguishes IHPTET from more traditional defense R&D programs is the degree of coordination across Services and demonstration projects. While the applications and the specific capabilities of the three classes of turbine engines are distinct, they share much of the same underlying technologies. Some examples of these areas are fans, compressors, combustors, turbines, mechanical systems, control systems, structural design, exhaust systems, instrumentation, and advanced materials. For each area, IHPTET has designated a panel of representatives from the participating Services and agencies to coordinate and establish objectives and timetables consistent with the ultimate performance goals for each class of turbine engines.

In addition to improvements in performance, IHPTET also pays considerable attention to other important facets in the fielding of advanced weapon systems: manufacturing and maintenance. In this era of tight defense budgets, any new weapon system, no matter how technically superior its capabilities are, must remain affordable if it is to be fielded. This applies to both the costs of production and any subsequent support costs. The use of advanced materials in IHPTET engines necessitates the development of improved manufacturing processes. Superior maintenance performance is being pursued by focusing on the development of robust, long-life components and enhanced field maintenance procedures.

Funding for the individual initiatives is controlled independently by the Services, NASA, and ARPA, though considerable consultation and coordination take place during the planning. Cost sharing is not specifically a part of the program, but in practice up to 40 percent of costs of the demonstration projects have been picked up by the commercial vendors. R&D contracts are awarded on a competitive basis, and while some teaming arrangements have been made, there are no explicit provisions for joint research typical of consortiums such as MCC and SEMATECH.

Currently, IHPTET is well into its second program phase (the first phase of the program successfully met all of its goals), and it claims that achievements are readily applicable to engines for the F-14, F-15, F-16, and F-117, although no evidence yet exists that this will in fact be the case. In terms of dual-use, traditionally there has been a considerable lag between the development of advanced engines in military systems and their application to civilian counterparts.[17] While theoretically plausible, it is too early to tell what precise impacts IHPTET will have on the civilian aircraft engine industry.

3. Very High Speed Integrated Circuit (VHSIC)

The VHSIC program, which began in 1980 and ended in 1990, was a response to the perceived gap between the application of state-of-the-art electronics technology in the civilian and military sectors. Whereas in the 1950s the nascent microelectronics industry depended heavily on military sales, by the end of the 1970s commercial applications had far outstripped defense demands and become dominant in determining the nation's research agenda. If the Pentagon wished to influence R&D in a more militarily useful direction, it needed to subsidize the research directly. Simultaneously, because of the ever increasing gestation period for the design and development of the Services' major platforms, fielded systems with microelectronics technology appeared primitive compared with that available in commercial products.

The ultimate objective of VHSIC was to decrease and perhaps eliminate the lead time between the appearance of advanced ICs in commercial products and in military platforms. This objective was to be accomplished through the use of R&D and demonstration contracts with semiconductor companies and defense contractors. Special arrangements were made to ensure that traditional DoD electronics vendors were teamed up with merchant semiconductor firms with a more commercial focus. The belief was that by doing so DoD could leverage the advances being made on the commercial side of the industry more quickly on the military side. The initial plans also envisioned a substantial diffusion of technical know-how among the participants. No specific arrangements were made to push for the incorporation of successful technical advances into fielded systems. The idea was that the Services, once they saw how wonderful VHSIC was, would clamor to have the technology employed in their platforms as quickly as possible.

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17 Note that unlike electronics, aircraft engines is an area where the military systems remain technically superior to civilian systems.

Formally, the funding for VHSIC was completely from DoD; however, participating firms also contributed resources to advance their particular goals. Projects were awarded to contractors at each phase of the program, and in all nearly $900 million was spent before the program ended. The implementation of the VHSIC program was itself accomplished through a four-phase plan:[18]

- **Phase 0:** Define the approaches necessary to reach the ultimate objectives of the program. This phase involved assessments of a set of military systems and subsystems, and analysis of their information processing requirements. It concluded with a broad outline of the VHSIC component that would meet those needs.
- **Phase 1:** Develop a complete set of prototypes and then create pilot production lines for the manufacturing of VHSIC chips.
- **Phase 2:** Refine VHSIC technology to sub-micron sizes and achieve a further 100-fold increase in performance capability.
- **Phase 3:** Conduct a VHSIC Technology Support Program to run parallel with the main project. The intent here was to use smaller and shorter-term R&D efforts to foster the development of allied technologies such as lithography and CAD essential to VHSIC.

While VHSIC was a high priority program of the Department of Defense that received ample funding and managed to obtain substantial support from Congress, at best it retarded the growing gap between commercial and military applications of microelectronics technology.[19] In hindsight, it is apparent that the design and implementation of the program undermined many of the critical objectives DoD was trying to accomplish.

First, the teaming arrangements that were designed to provide incentives for commercial semiconductor firms ended in near total failure. Of the six commercial firms that participated in Phase 0 of the program, only Motorola was left by Phase 2. In addition, traditional military electronics vendors managed to capture the bulk of the funds for the program.

Second, the goal of disseminating technical know-how among VHSIC participants in particular, and the industry in general, clearly conflicted with its status as a military R&D program. Despite the clear dual-use nature of VHSIC projects, the

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[18] Kubbig 1988.

[19] The discussion here draws heavily from Alic et al. 1992, chapter 8.

restrictions with respect to secrecy severely limited the diffusion of the knowledge gained. While VHSIC was supposed to encourage interfirm cooperation and technology transfer, in the end it resembled most other military R&D efforts. Even when one focused solely on the objective of improving military electronics, the program has accomplished little.

Third, the most critical problem was a failure to recognize and change the institutional barriers to the acquisition of advanced commercial technology. The gestation period for most modern weapon systems is often 10 or more years, a veritable lifetime compared with that of commercial electronics. To ensure the use of up to date electronic circuitry when a weapon system is in production, a program manager must make a commitment to VHSIC components that exist only on a drawing board. Given a system that rewards only success, program managers in the Services were inevitably driven to avoid risk and rely upon proven technologies instead.

4. Microelectronics and Computer Technology Corporation

Unlike the other programs we have examined in this section, Microelectronics and Computer Technology Corporation (MCC) is a purely commercial R&D effort. It is relevant to our discussion because it demonstrates that even without government support, industry may be motivated to enter into alliances that defray the costs and risks associated with R&D investments, and its performance provides a commercial benchmark for understanding the efficacy of this organizational form of endeavor.

Founded in 1982 by a consortium of this country's then most important computer hardware and software manufacturers, MCC was chartered to help maintain American leadership in the computer industry. It was a direct response to the 5th Generation Computer Systems Project sponsored by MITI and the major Japanese computer and electronics companies. The ultimate goal of the Japanese program was to design the next generation computer system, an intelligent computer. Such a project, if successful, would have allowed Japan to leapfrog the U.S. in computer technology.

The current shareholders of MCC are 3M, AMD, Andersen Consulting, AT&T, Cadence, Ceridian, DEC, Kodak, GE, Harris, HP, Honeywell, Hughes, Lockheed Martin, Motorola, National Semiconductor, Nortel, and Westinghouse. The annual budget is over $50 million. MCC's current research agenda can be broken down into two areas: (1) packaging and interconnecting technology, and (2) software R&D programs in advanced data base technology, signal processing, and intelligent systems. Following are examples of ongoing projects:

- Low Cost Portables Program
- High Reliability Mobile Electronics Program
- Workstations and Multiprocessors Program
- Intuitive Interfaces to Information Systems (I3S)
- Infosleuth: Networked Exploitation of Information Using Semantic Agents
- HyMPACT: HyperMedia Presentation Authoring and Composition Technologies Project
- Interoperability in Global Networks

Like its Japanese counterpart, MCC began with a very broad, almost revolutionary research and development agenda. Over time, its goals, like those of its Japanese counterpart, have become far more modest. In fact, much of its work has been the development of technologies that its original corporate partners did not find commercially attractive to pursue by themselves.[20]

While MCC has made some major contributions to electronic packaging and interconnections, it has not achieved similar success in computer architecture, CAD tools, and software development. A persistent problem is the difference in the visions of the founders of MCC and the managers that have been responsible for creating and implementing the actual research programs. While the founders envisioned long-term (5-to 10-year) revolutionary advances in the development of hardware and software, the actual managers that constructed MCC's R&D program did so with a much shorter time frame (1 to 3 years) in mind. James Gover, in his analysis of industry consortia, argued that—

> MCC's failure to live up to their member's expectations may well have been determined by the fact that their members were competing in businesses where commercialization is driven by product and process improvements, yet MCC was focused on research that would lead to major breakthroughs in technology. Neither consortia nor central corporate research laboratories have been able to successfully implement a breakthrough strategy in sectors where commercialization is driven by the need to improve products and processes.[21]

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[20] Lynch 1993, 225.

[21] Gover mimeo, 26.

In reality, the disappointment with MCC may well be due to the unrealistic lofty expectations held by its founders. (Note that, in a similar vein, the Japanese 5th Generation project is also widely perceived to be a failure.) The problems of intelligent systems, in retrospect, have turned out to be far more difficult than many AI practitioners believed 15 years ago. Furthermore, the competitive structure of the industry has changed radically since then. A part of MCC's problems may also have been the paradigm it operated under, one that was shaped in large part by firms that turned out to have missed the boat.

5. Lessons

The foregoing four programs provide some interesting insights into how the government might go about implementing an R&D program designed to address national objectives. We offer the following observations and comments.

- SEMATECH's strategy, from the government perspective, is *industrial base strengthening*. While defense was used as a justification for the program, nothing specific was done to integrate the fruits of the program into military systems. In fact, it is hard to imagine how the program would have been any different if the operative motive for government involvement was industrial policy rather than national security.
- IHPTET is problematic for all four of the dual-use program categories we introduced in Chapter 2, with *purposeful spin-off* being the closest fit. In fact, the program is probably best categorized as serendipitous spin-off—that is, while the program trumpets the dual-use nature of aircraft engines, the goals and funding of IHPTET are rather like any other traditional military R&D program. Any eventual commercial applications that result from IHPTET are likely to be incidental and not as a result of specific provisions of the program.
- VHSIC may be classified as an unsuccessful effort at *indirect spin-on* and *purposeful spin-off*. Clearly, the goal of DoD in this instance was to leverage the enormous advances in the commercial microelectronics industry into military systems, and ultimately, if the program proved to be successful, allow the advances made to filter back to the commercial side.
- MCC demonstrates that the conduct of R&D activities within the framework of a consortium, even by the private sector, is difficult. In particular, the disappointment with MCC may well be due to the unrealistic lofty expectations held by its founders.

We believe that the three following lessons about the use of consortia as programmatic vehicles to promote dual-use are also important.

First, the goals of the program must be very specific and concrete, and the mechanisms used for implementation must directly support fulfillment of these goals. In the case of MCC, the initial vision was simply too speculative. With VHSIC, the problem was identified correctly and the goal was concrete, but the design of the program didn't really address the true cause. No one recognized that the principal source of the disparity between military and commercial electronics lay not in technical know-how, but in the system of incentives behind the development and procurement of weapon systems. SEMATECH has been able to accomplish what it has because it recognized early on that the critical issue was the competitiveness of the semi-conductor manufacturing equipment industry. With IHPTET, the goals of the program were clear and objective. Inter-Service collaboration ensured the proper level of coordination, while independent control of R&D funds reduced conflicts and incentives to closely monitor and manage the private vendors.

Second, the R&D objectives of a consortium must not be the principal source of competitive advantage among the participants in the program. Imagine what the implications would have been if any one of the computer companies that founded MCC had been able to successfully accomplish, on its own, the objectives set out by MITI's competing effort? There should be little doubt that such a firm would have enjoyed dominance in the industry that even a Microsoft would envy. This being the case, is it any wonder that MCC ended up developing technologies that were deemed unprofitable by others? Looking at SEMATECH, it should be apparent that because the source of competitiveness among the private sector members lay in the design of semiconductors rather than in manufacturing efficiencies, they could work together on R&D efforts directed principally at their suppliers. While IHPTET is not a research consortium, the role that the Services play closely resembles that of the semiconductor manufacturers in SEMATECH, while the engine vendors are akin to the semiconductor equipment makers.

Third, designing a successful, explicitly dual-use R&D program based on a private sector consortium or public-private partnership model *within* the current military acquisition system is likely to be difficult, if not impossible. None of the three government-supported programs reviewed was able to obtain dual-use benefits whose end-products were explicitly planned and accounted for. Serendipity, flexibility, opportunism, and pursuit of a goal—not a specific product, process, or technology—

appear to be the keys to success. For reasons we have already discussed, VHSIC, which had clear dual-use intentions, principally spin-off, was generally unsuccessful in its efforts. However, a program like IHPTET, where dual-use is incidental and the real goal is turbine performance by the best technical means, is more likely to be successful. As for SEMATECH, while its goal is asserted to be critical to national security, it is not clear how its success or failure affects the capabilities of the relevant subsystems of current or future military platforms. While the threat to national security has been used as a justification for public funding, it remains unclear to us how national security concerns impact how SEMATECH functions.

C. IMPLICATIONS FOR DUAL-USE PROGRAMS

The interwar period demonstrates that close collaboration between the U.S. government and industry—U.S. and foreign—may yield important benefits for national security. Within an environment less fettered by acquisition regulations and concerns about ideological correctness, it was possible to quickly identify pragmatic solutions to problems and sensible working relationships to pursue goals important to both the military and commercial sectors. But more to the point, when government and industry failed to collaborate closely, as in the case of radar, important opportunities were lost. This suggests that rewriting laws and relaxing regulations will not be enough to ensure a successful dual-use investment strategy, and institutional and cultural issues remain important.

The record of consortia as vehicles for making dual-use investments also offers important lessons for policy makers. In government-inspired constortia, when goals are clear and the members also stand to gain from participation, as in the case of IHPTET, favorable results generally result; but even when goals are clear, if the members of the consortium are not those who will utlimately benefit from its activities, as in the case of VHSIC, outcomes are much less satisfactory. In industry-inspired pre-competitive consortia, such as MCC and SEMATECH, there is an internal competitive dynamic that drives outcomes—firms seek to collaborate only where no single member of the consortium is conferred a comeptitive advantage in the marketplace. Dual-use programs relying on consortia, therefore, must consider not only objectives, but organizational dynamics and membership composition to increase chances for success.

D. SUMMARY

- Recent commotion about the use of commercial technologies for military purposes, and the commercial benefits from defense investments, ignores the fact that, until the post-World War II period in the United States, commonality across these sectors was more the rule than exception. Indeed, technological advances have historically flowed between the two sectors.
- The historical antecedents to the current effort to encourage dual-use date back to the period between the end of World War I and the eve of World War II, a period during which the defense research and development environment was similar in many respects to today's. The years between 1918 and 1939 were the last extended period of military planning absent a major, strategic threat from the Soviet Union. Americans were confident of their near-term strategic security; and while they recognized the possibility that Germany and Japan were potential threats, Americans generally felt that threat was distant.
- The 1920s and 1930s were much simpler times in many respects, not the least of which was in the rudimentary nature of the military research, development, and procurement process. For this reason, hard parallels between the interwar experience and today's effort to force dual-use policies are difficult, if not impossible, to draw. Nonetheless, the interwar experience offers valuable insights into the advantages, disadvantages, benefits, and risks of direct collaboration among the government, the military, academe, and private industry in the advancement of new technology that bears the potential of great payoff for all the elements concerned.
- The history of the development of radar demonstrates, inversely, the advantages of inter-Service and civilian-military cooperation. The United States made impressive advances in radar technology by the eve of World War II, but its technological advantage in this area could have been insurmountable—in, for example, the development of a wartime IFF capability—had true cooperation taken place from the beginning of the research and development effort. The development of radar was initiated at a time when the Navy was moving away from its earlier practice of close cooperation with, indeed principal reliance on, industrial research and development—direct and indirect spin-on.
- The story of penicillin production constitutes a dramatic success story that makes essentially the same case as radar: Centralization of effort can bring huge payoffs in time and level of success and does not need to threaten the incentives of private industry. It is not clear that the large-scale production of penicillin would have happened at all without the intervention of a close government-industry alliance—an example of indirect spin-on. In any case, penicillin production would have stayed on a very low level throughout the

war, providing little more than the minimum necessary to treat only the most severe wartime injuries

- The amphibian vehicle example suggests a similar lesson: Cooperation can provide benefit to both the military and the civilian industry involved—in this case through direct spin-on. Both Roebling and Higgins had inventions with limited economic promise in the civilian sector. The Marine Corps had a very specific technical problem upon which its entire operational concept hinged, but it did not have the institutional means to develop the necessary capabilities in-house. Fortune brought the Marines, Higgins, and Roebling together, but common sense and close cooperation, unhindered by overregulation and overspecification, provided a solution to all their problems.
- Our experiences with radar and long-range bomber development show that short-term investment in cooperative research and development can bring enormous long-term dividends that cannot be foreseen at the time—examples involving direct and indirect spin-on, purposeful spin-offs, and ultimately industrial base strengthening. The civilian aviation and air travel/transport industries that constitute such an important part of the modern world economy would have been impossible without the technological advances made as a result of military research and development of radar and long-range aircraft. Likewise, the limited resources that the Army Air Corps pumped into the infant aviation industry during the 1920s and 1930s nurtured that industry through its early stages of steep learning curves, small markets, and marginal economic payoffs.
- A central question in the debate on dual-use and the industrial base is, How can the federal government best pursue technology goals that it believes are critical to national well-being through the use of inter-organizational collaboration, particularly the employment of government-industry and industry-industry consortia?
- SEMATECH's strategy, from the government perspective, is *industrial base strengthening*. While defense was used as a justification for the program, nothing specific was done to integrate the fruits of the program into military systems. In fact, it is hard to imagine how the program would have been any different if the operative motive for government involvement had been industrial policy rather than national security.
- IHPTET is problematic for all four of the dual-use program categories we introduced in Chapter 2, with *purposeful spin-off* being the closest fit. In fact, the program is probably best categorized as serendipitous spin-off—that is, while the program trumpets the dual-use nature of aircraft engines, the goals and funding of IHPTET are rather like any other traditional military

R&D program. Any eventual commercial applications that result from IHPTET are likely to be incidental and not as a result of specific provisions of the program.

- VHSIC may be classified as an unsuccessful effort at *indirect spin-on* and *purposeful spin-off*. Clearly, the goal of DoD in this instance was to leverage the enormous advances in the commercial microelectronics industry into military systems and, ultimately, if the program proved to be successful, to allow these advances to filter back to the commercial side.
- Unlike the other consortia programs examined in this chapter, MCC is a purely commercial R&D effort. It is relevant to our discussion because it demonstrates that even without government support, industry may be motivated to enter into alliances that defray the costs and risks associated with R&D investments, and its performance provides a commercial benchmark for understanding the efficacy of this organizational form of endeavor—the conduct of R&D activities within the framework of a consortium, even by the private sector, is difficult. In particular, the disappointment with MCC may well be due to the unrealistic lofty expectations held by its founders.
- The interwar period demonstrates that close collaboration between the U.S. government and industry—U.S. and foreign—may yield important benefits for national security. The experiences of that time also show that it will take more than rewriting laws and relaxing regulations to puruse a successful dual-use investment strategy, and that institutional and cultural issues remain important. Moreover, dual-use programs relying on consortia must consider not only objectives, but also organizational dynamics and membership composition to increase chances for success.

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V. FOREIGN TECHNOLOGY/DUAL-USE POLICIES AND DEFENSE INDUSTRY GLOBALIZATION

Since World War II, national security and economic strategies have been pursued in one form or another by virtually all governments. Over the years these strategies evolved according to the political, economic, and social circumstances particular to each country. Europe and Japan, for instance, formulated explicit economic development strategies based upon mixed market economies as their means to reemerge from the devastation of World War II. These programs matured and changed over time, but to this day they maintain key features regarding the focus and the manner of government involvement. This is true despite the fundamental post-war evolution in the geopolitical and geoeconomic factors underlying U.S., Japanese, and European interactions; by and large the overarching mechanisms, organizations, and structures established in the immediate post-war years have not similarly transformed.

The significance of foreign approaches to dual-use is threefold. First, the relationship between industry and government is much closer in other nations than it is in the United States, and as a consequence U.S. defense firms are likely to face stiff, government-subsidized competition in the international arms market—not just as regards dual-use, but in all aspects of military sales. Second, the post-Cold War period appears to be one in which technology control regimes are more relaxed, and the transfer of dual-use technologies for military purposes under the guise of commercial applications is much more likely—this opens the opportunity for technology and advanced arms transfers to U.S. adversaries. Third, the pursuit of an increasingly integrated, dual-use industrial base portends greater dependence on foreign technological and industrial capabilities—a traditional concern for U.S. military planners.

This chapter begins with a general overview of the comparative experiences of other nations as they have sought to address national technology policies. While this discussion is far ranging and extends to topics well beyond the focus of this paper, it is included here because of its importance to understanding the implications of differing national political environments for the adoption of dual-use national security strategies. We focus on Japanese and European technology policy as representative of the types of "national" systems found in the developed world. Chapter 6 then explores case studies of dual-use activities in Japan, China, the U.K., and Brazil.

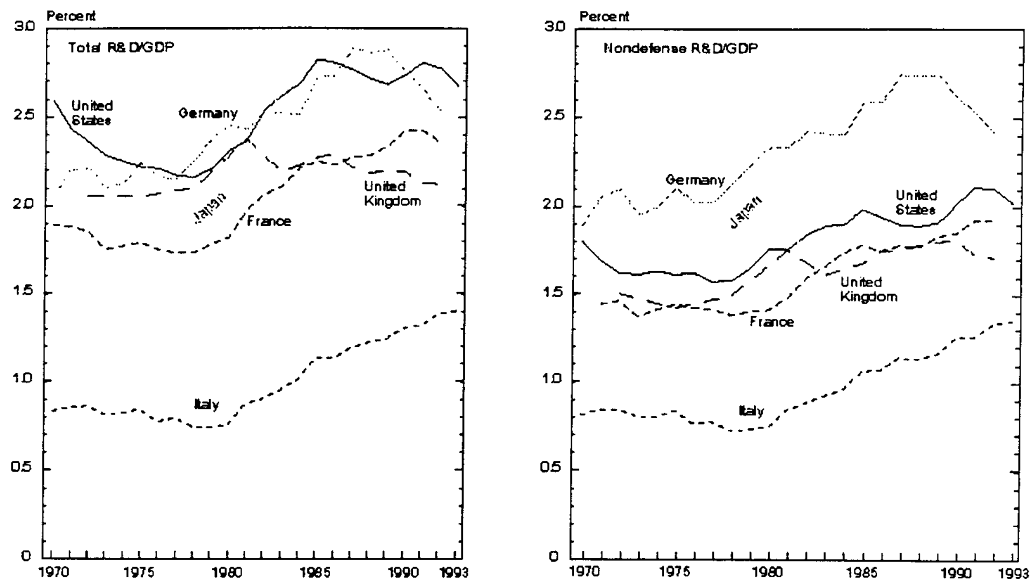
Government policies are but one dimension of the global aspects of dual-use; multinational enterprises (MNEs) are in fact the primary conduit for transferring technologies across national boundaries. Recognizing that reality, we consider the impact of such commercial-sector entities on a government's ability to control the flow, recipients, applications, and accessibility of advanced dual-use capabilities. Whereas national technology policies set the stage for commercial practices, the activities of these organizations represent the fabric of commercial enterprises that are increasingly transnational.

The chapter concludes with an assessment of the implications of globalization[1] for U.S. national security as this relates to increased ease of access to advanced dual-use capabilities.

A. COMPARATIVE INTERNATIONAL TECHNOLOGY STRATEGIES

In pursuit of national security goals in the Cold War era, U.S. security strategy stressed technologies with military utility; indeed, approximately one-half of all U.S. government R&D funding in the post-war period was spent for military purposes (Figure V-1). Research and development as a commercial economic driver during this period was left primarily to private industry, although benefits from military R&D accrued to the civilian sector through serendipitous spin-off. Despite these divided emphases, for several decades after the end of World War II the United States remained globally preeminent in both the commercial and military realms. Such success was based upon the relatively undamaged U.S. economy that emerged from the war, spin-off benefits from significant technological advances during the war, and the unique position as "supplier to the world" of manufactured products not yet in production in the recovering economies of Europe and Asia.

1 The discussion of globalization draws heavily upon White and Tai 1995.



Source: National Science Foundation

Figure V-1. R&D Spending (By Country) As a Percentage of GDP

The United States was generous in its new post-war role as the de facto leader of the "free world," emphasizing the reconstruction of not only the economies of the Allied nations, but also those of the Axis as well. U.S. policies stressed concentration on economic matters in those nations, while U.S. military might provided a shield against such adversaries as the USSR and China. These divergent strategies manifested themselves in different long-term behavior for the U.S. versus other market economies. The U.S. post-war technology strategy centered on military security, while the other market nations emphasized economic growth.

As a result of over 40 years of rebuilding and restructuring the market economies, the U.S. no longer stands head and shoulders above its allies in terms of technological sophistication or economic competitiveness. While we have only just begun to recognize the signs, for more than two decades our chief economic rivals in the free world have become less dependent on the United States for a variety of products, services, and know-how. *We are now in the long run.* That is, henceforth the U.S. will compete on a relatively even footing with other advanced nations, and the outcome of this competition will be a function of this nation's ability to adapt to and correctly anticipate a rapidly changing world.

1. The Japanese Experience

The pre-World War II Japanese economy may best be characterized as playing "catch-up" to the Western industrial economies of the period. From an agrarian start in the 1850s, Japan was capable of producing a navy that, in 1905, challenged and sank a Russian fleet of warships in the Straits of Tsushima. Such dramatic economic and military growth was, in large part, attributable to the regimentation of Japanese culture, its devotion to duty, single-mindedness in achieving goals, and strong central direction of industrial efforts on the part of the Meji government.

In terms of military technology, the Japanese built and fielded a capable and advanced air force and navy in the 1920s and 1930s. These forces were used to assist the nation in satisfying the significant appetite for raw materials and imports needed to fuel the continuation of strong economic growth. Ultimately, Japanese expansionism was tested and defeated in World War II.

After World War II, a new, demilitarized Japan turned its efforts to rebuilding a strong and versatile economic and technology base. Its industries had been devastated by war, its constitution prohibited it from fielding a large, offensive military, and it looked to the United States for protection. The Japanese government channeled national efforts into long-term economic gains rather than national security. Ironically these U.S.-guided redevelopment efforts were based largely on principles of government-industry cooperation that the United States, itself, eschewed. The successes and failures of Japanese industrial policies have been well documented by such scholars as Chalmers Johnson, Daniel Okimoto, and Clyde Prestowitz. From these we distill the following general arguments.

Government-industry cooperation after World War II was not alien to Japanese economic culture; in fact, it fit easily within the emerging post-war system of kiretsu—strategic business alliances between firms involving production, finance, labor and marketing. In fact, the effect of the kiretsu system appears to have been at least as successful in marshaling and employing resources as the pre-war zaibatsu—large, *integrated* corporations that embodied all of the functions of production, finance, labor, and marketing. Most important, as emphasized by Okimoto, the Japanese recognized the central role of technology as the primary determinant of competitiveness among firms and its conference of "comparative advantage" in trade.[2]

Throughout the entire post-war period, the Japanese government's economic development strategy for its commercial industries has stressed the development of competence and strategic positioning in key economic activities and technologies. A strong government economic bureaucracy, and in particular efforts on the part of the Ministry of International Trade and Industry and Ministry of Finance, have actively promoted various strategies for economic growth, with implementation based upon the Japanese tradition of consensus decision making. As such, Japanese technology policy has provided a "framework for activity," but contrary to common perception, relatively little direct financing.

During different periods of post-W.W.II development this framework included import protection, restrictions on foreign investment, assistance in licensing overseas technology, measures to reduce barriers to entry for domestic firms, and so forth. Also, the Japanese government's role as a consumer has been important, particularly in telecommunications and aerospace. Within Japan itself, intense rivalry between large industrial groups today drives responses to new opportunities with emphasis on long-term market share. Until recently the relatively low cost of funds for investment reinforced this long-term investment approach.

The Japanese experience has not been a total success, however. Because it has maintained a large agricultural sector and small retail business units, the nation pays a significant price in terms of production and distribution. Furthermore, not all Japanese workers are guaranteed lifetime employment, and many of those who are depend heavily on bonuses to make ends meet. The Japanese have been especially successful compared with the United States, however, in the area of human capital, their work force is exceptionally well disciplined and individually capable of learning and carrying out new tasks with minimal supervision. This is perhaps the key to the rapid assimilation of new technologies in the workplace and continual improvements in quality and productivity.

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2 Okimoto 1989, 27 and 30–31. This theme is also echoed by Shintaro Ishihara in *The Japan That Can Say No*.

2. The European Experience

The European experience with economic development strategies after World War II appears similar to that of the Japanese. As in Japan, European economies were rebuilt with the aid and under the protection of the United States. And like Japan, European governments had a direct role in planning their economic recovery at the behest of the United States. But beyond this simple characterization, real differences emerge.

Unlike the Japanese experience, the European one is difficult to characterize as a single unit (even since EC 92). Germany is generally viewed as the leading economy, but France, Italy, and the U.K. are also major players. Furthermore, Spain's relatively recent admission to the European Community has led to significant gains in its overall economic position. And the economic policies across the different European nations are varied with significant differences in their emphasis.

The European economy has always been more open to U.S. economic interaction and influence than has that of Japan. This openness comes from a long tradition of trans-Atlantic commerce hailing back to colonial America. It is largely a cultural phenomenon that derives from common underlying assumptions regarding the role of trade and foreign investment in strengthening national economies.

Technology policies in Europe, on the other hand, have paralleled the Japanese experience more so than that of the United States. European economies almost universally have experimented with varieties of socialism and social democracy, and public sector intervention in economic development of the national economy has thus been seen as ideologically integral to a number of Europe's post- World War II governments. Investments in research and development are heavily weighted toward commercial developments rather than defense, and they largely reflect the greater integration of commercial lines of business with defense production activities.

Still, Europe, like the United States, faces difficulties in bringing new products to market and financing expensive next-generation technologies within the private sector. These difficulties result from the relatively limited number of large European corporations—by global standards most European businesses are medium-sized. The smaller scale of high-tech European companies has been offset to some degree through cooperative ventures and co-development activities. In the defense realm, joint development of the Jaguar, Tornado, and Alpha Jet aircraft are examples; in the civilian realm Airbus Industries stands out. Perhaps the most important admission of the need to increase the overall scale and integration of European enterprises was the unification of Europe under the Single European Act, EC 92.

To pursue the development of promising technologies, the Europeans have also entered into numerous cooperative research efforts, for example, JESSI and ESPRIT and BRITE.[3] Such programs are a sign of recognition that intensive efforts in key technology areas may have significant positive benefits for business and society at large. The results of these efforts are uncertain, however, and they tend to suffer from the "too many cooks" problems that plague many joint development efforts.

Because of multinational involvement, European efforts to develop and execute technology policies are not uniform. For instance, the U.K. and France have been described as "mission oriented" toward goals of national importance; Germany, Switzerland, and Sweden, as "diffusion-oriented." Mission-oriented policies concentrate on "strategic importance"; "diffusion-oriented" policies are decentralized with little in the way of specific technical objectives. The latter emphasize industry-research cooperative R&D and focus on public goods to spread technological capabilities.[4] Neither of these orientations applies to Japan, which has been characterized as both diffusion and mission oriented.

B. MULTINATIONALS, DUAL-USE, AND NATIONAL SECURITY

While it is convenient and "clean" to think of technology as a national domain, in fact it is now a global domain, and the foregoing discussion of national technology strategies must not be confused with strict control over global technology flows and economic interactions. In fact, the more global economic and technological endeavors become, the less appropriate it is to view production activities as a simple pyramid of companies engaged in producing and assembling components and parts to yield completed products. For defense this is already true in the U.S. because weapon system designers and producers are no longer necessarily the same at any level of fabrication or assembly. Under a global production regime, weapon system design is not the responsibility of one firm or a small set of firms; rather, it is likely to be dispersed worldwide to take advantage of technical specialties of many participants. Similarly, fabrication,

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3 National Research Council 1991. Joint European Submicron Silicon Initiative (JESSI); European Strategic Program for Research and Development of Information Technologies (ESPRIT); Basic Research in Industrial Technology for Europe (BRITE).

4 Ergas 1987, 191–245.

assembly, and research and development activities may become displaced should the level of interconnectivity mature sufficiently.

Such arguments lead to a conception of global defense industrial activities within the context of grand endeavors cutting across national boundaries. The global dispersion of design and production activities introduces new and critical issues for the success of dual-use policies and the development and deployment of advanced, affordable weapons and systems for the U.S. military. Defense industry globalization suggests that profit-making enterprises will seek competitive advantages by relying on the lowest cost sources worldwide, regardless of geographic location. Firms that do not engage in such efficient forms of collaborative behavior will not survive in the global marketplace.

The Office of Technology Assessment recently completed studies of multi-national enterprises (MNEs) in which it offers the following observations relevant to the proliferation of dual-use technologies across national boundaries:

> The modern MNE is a highly flexible and adaptable form of business organization. It can take many different forms . . . MNEs configure and reconfigure their operations to meet diverse requirements, including those imposed by different governments, or to take advantage of opportunities and inducements offered to them be governments.
>
> [B]road asymmetries in the policy regimes of the major trading nations have developed—especially market access, foreign direct investment, financial, and industrial policies related to the activities of MNEs.
>
> Many MNEs are increasingly "multi" and less "national" than in the past; there appears to be a growing divergence of national needs and the needs of these MNE organizations [and the] interests of U.S.-based MNEs frequently diverge from the U.S. national interest at least in part because the U.S. government has not specified what that interest is.[5]
>
> Unlike other principal activities of MNEs, research and technology development tends to be concentrated in the country of national origin. U.S.-based MNEs, for example, conduct less than 13 percent of their manufacturing R&D abroad. Although no comparable data exists for European and Japanese MNEs, the available evidence suggests that they

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5 U.S. Congress OTA 1993, 13–14.

conduct similar if not smaller percentages of their R&D overseas than do U.S. firms.[6]

One approach to dual-use is to promote the close collaboration of commercial and defense firms for the purposes of developing militarily-relevant technologies and transitioning them into commercial products and processes. In many cases, the firms involved in these alliances are large MNEs with substantial foreign interests. In addition to foreign components, these MNEs tend to engage in a substantial number of cross-border collaborative business relationships. The degree to which these foreign interests and relationships may adversely affect U.S. national security depends on the nature of the cross-border collaborative activities, the availability of alternative domestic capabilities, and whether or not foreign firms are acting openly. Since, such alliances are driven by intense market competition and many of them contain or will contain MNEs, the composition of dual-use defense-commercial teams must be carefully crafted where foreign participants may benefit indirectly from U.S. government investments. To facilitate discussion of the various cross-border relationships, we categorize them as foreign sourcing, cross-border alliances, and foreign direct investment.

1. Foreign Sourcing

Foreign sourcing by defense industries may be broadly characterized as the use of foreign-supplied components, items, or processes for the production of weapons systems. We may distinguish foreign sourcing from foreign dependence in that domestic suppliers are available but not used. Whether or not citizen-owned offshore activities are "foreign" is itself a topic of constant discussion.

From the *businessman's* point of view, foreign sourcing is simply a matter of relying on foreign firms for the research, development, marketing, or production of products, components, or technologies. Unlike businessmen, U.S. defense planners look askance at the use of foreign firms to supply the military because it is critical that conflict-related production demands be met in the event of war. From a narrow national security point of view only domestically based, domestically owned sources of supply are truly "secure"; some may argue, however, that any domestically based firm is secure regardless of ownership.

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6 U.S. Congress OTA 1994, 2.

The importance of foreign sourcing to national security is a function of its positioning within the overall regime of weapon system production. Security concerns related to foreign sources' delivery of finished weapons systems must be distinguished from those associated with the delivery of components or the conduct of research and development. Furthermore, the temporal characteristics of the weapon system's production must be considered to determine overall sensitivity.

Consider the case of long lead time weapons, a category that includes virtually all high technology arms. For short duration conflicts, stockpiling finished systems and repair/replacement components could allow a nation to field foreign-produced items with little if any risk to overall national security.[7] Regardless of where production takes place, the additional quantity of arms that may be produced is unlikely to arrive in time to be militarily significant. For lower tech materiel that require shorter lead times and that are not likely to be stockpiled in large quantities, such as battle dress uniforms, chemical suits, and meals ready to eat (MREs), a domestic source may be deemed important to provide flexibility and ensure continued supplies. Conversely, if long-term conflicts are anticipated where foreign supplies are uncertain, there is no adequate replacement for domestic production capabilities.

While foreign sourcing may not pose immediate threats to national security, in the long run considerable problems may arise if the development of new military technologies moves offshore along with production. In such a case the defense technology infrastructure may erode, leading to the deployment of less capable systems in the future. Additionally, foreign weapons producers benefit from the expatriation of research and development, allowing potential U.S. adversaries to field more capable weapons of their own.

The United States, for instance, is today becoming technologically "vulnerable" to the foreign policies of its current allies—Europe and Japan. While much of the concern is the product of political hyperbole, such as Shintaro Ishihara's claim that "without using new-generation computer chips made in Japan, the U.S. Department of Defense cannot guarantee the precision of its nuclear weapons,"[8] longer term concerns may be real. For instance, the Defense Science Board in 1989 expressed worries about increased U.S. dependence on "foreign" produced integrated circuits: only 25 percent of DoD integrated

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7 See Chapter 2.

8 Ishihara 1989, 21.

circuits are manufactured onshore; most "piece parts" going into integrated circuit fabrication other than the die are produced offshore; and "95 percent of all Standardized Military Drawing (SMD) die are produced in offshore facilities owned by U.S. firms."[9]

In the long view, a balance needs to be struck between the clear cost and technical advantages that may accrue from employing foreign production and technological capabilities, and the loss of domestic technical know-how and skills that occurs when production or research is moved offshore. If only short wars with short warning times are anticipated in the future, the optimal approach would be to minimize the degree to which the United States pursues "arsenal" policies when clearly superior foreign capabilities may be procured.

2. Cross-Border Alliances

Another manifestation of globalization is the cross-border corporate alliance, defined here as virtually any cooperative venture or activity between domestic and foreign firms, be it in research, production, marketing, etc. Such alliances are perhaps the greatest indicator of the growing global nature of today's defense industrial base and are not simply first-world phenomena.

The European approach to defense production, for instance, may be best characterized as "on-again, off-again" cross-border alliances initiated by governments to meet the large resource requirements of high technology weapons systems development. Such alliances led to the development of the Alpha Jet, Jaguar, and Tornado aircraft. The European Fighter Aircraft (EFA) is a joint development program involving the U.K., Germany, Italy, and Spain. EFA, in fact, is heralded as "the biggest collaborative defense program ever undertaken by NATO, with [r]adar . . . to be provided by GEC Marconi of the U.K., avionics and cockpit displays by GEC Avionics and Smiths Industries of the U.K., weapon interfaces by MBB of Germany, and V/UHF communications subsystems by Rohde & Schwartz of Germany." Alenia of Italy and CASA of Spain had secured numerous contracts for other subsystems.[10] The goal is to develop a technological synergy to deliver capabilities beyond those of any one of the partners.

Alternatively, Japanese military production has tended to rely on a series of co-production and licensing agreements with the United States for its high technology

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9 Department of Defense 1989a, 6.

10 Cook 1992, 480.

weapons systems, although within the past decade it has also begun to apply its considerable commercial technological capabilities to meet national defense needs.[11] For instance, Japan sought permission to increase the number of aircraft it is allowed to produce under license from the United States, including the Bell/Fuji AH-1S and Sikorski/Mitsubishi SH-60J/UH-60J helicopters, the McDonnell-Douglas/Mitsubishi F-15J fighter, and the Lockheed/Kawasaki P-3C Orion aircraft.[12] In addition, it is producing moderate quantities of indigenously designed air-to-air missiles based on U.S. systems, including the AAM-3, SAM-1, and Keiko SAM.[13] However, behind the willingness to enter into co-production agreements is an active government effort to apply foreign military technologies to commercial pursuits. In this regard the FSX, an indigenous Japanese fighter aircraft that is derivative of the U.S. F-16, is viewed by some as primarily a technology transfer ploy to support an incipient Japanese commercial aircraft industry.

Today, some newly industrializing countries and some less developed countries have also joined developed nations in demanding co-production of weapon systems they are purchasing from abroad. For instance, U.S. co-production of the F-16 includes Belgium, Turkey, Israel, South Korea, Indonesia, and the Netherlands.[14] Additionally, General Dynamics agreed to assemble 50 complete F-16 aircraft under license in South Korea as part of a competitive sales enticement for that nation. Argentina and Egypt have cooperated in the development of the Condor ballistic missile, apparently aided by MBB of Germany.[15] Taiwan has sought the aid of U.S. defense firms to develop its Indigenous Defense Fighter,[16] while Chile is cooperating with Royal Ordnance of the U.K. to develop a truck-mounted rocket artillery system.[17] The United States has even expressed interest in obtaining a wide range of Commonwealth of Independent States (C.I.S.) military technologies to avoid costly duplication of research. All of these arrangements

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11 U.S. Congress OTA 1990, 66.

12 *Aviation Week and Space Technology*, 13 April 1992, 11.

13 U.S. Congress OTA 1990, 66.

14 U.S. Congress OTA 1991, 42–43.

15 Carus 1990, 22.

16 Proctor 1992, 38–39.

17 Foss 1992, 281.

lead, to some degree, to technology transfer as well as to the training of foreign nationals in the production and integration of military systems.[18]

From a national security standpoint, cross-border corporate alliances entail the same potential threats and benefits as foreign sourcing. In addition, however, it involves more intensive technology transfer activities, particularly in the process of establishing qualified production facilities in other nations. On the one hand, this may be viewed as a considerable threat to national security since both classified and proprietary information is made available to other nations, and there are the ever-present risks of intentional transfers of knowledge to potential U.S. adversaries. On the other hand, such activities do offer advantages that should not be ignored.

When a U.S. company sets up shop to produce weapon systems and their components overseas in allied nations, the advantages for national security come in several forms. One is the degree to which foreign markets may become amenable to the purchase of U.S. arms, a development which, in turn, increases the volume of production and lowers overall unit costs. Another is the potential for system interoperability worldwide with allied nations who maintain support and repair facilities usable by U.S. forces. The use of foreign qualified suppliers to provide for U.S. defense needs in times of national emergency—a literal extension of the U.S. defense industrial base—should also not be overlooked. And as foreign technology developments demonstrate world-class potentials, U.S. firms should not be proscribed from availing themselves of potential advantages for commercial and military purposes.

3. Foreign Direct Investment

If a company is unable to access a technology, capability, or product through license, co-production, or foreign sourcing, it may resort to investing in or acquiring another firm, an option referred to as "foreign direct investment." In recent years foreign acquisitions of U.S. firms in particular have taken center stage because of increased Japanese activities oriented toward buying U.S. real estate and entertainment industry assets. These business transactions are part of the considerable foreign investment in the United States in the past decade which totaled $15.2 billion in 1984, peaked at $72.7

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18 "Cooperating with foreign industry in the development and production of weapons builds up their indigenous defense industrial capabilities, transferring potent, advanced defense technology to foreign nations." U.S. Congress OTA 1991, 13.

billion in 1988, and was reported at an annual rate of $64.4 billion in 1990.[19] In the case of non-militarily relevant companies the U.S. government has regarded such activities as benign.

The national security implications are more troublesome, however, when the foreign acquisition involves a defense-relevant firm engaged in first or second tier military production. For example, when a consortium that included Thomason-CSF of France and the Carlyle Group of the United States tried to acquire the missile division of LTV Corporation, the U.S. government believed that the security of U.S. missiles systems could be compromised even if separate managements were set up to make ownership influence "arms length." The acquisition would have included the Theater High Altitude Air Defense, Multiple Rocket Launch, and Army Tactical Missile Systems, as well as components for the B-2 bomber.[20] A prospective deal involving the purchase of 40 percent of McDonnell Douglas by Taiwan Aerospace Corporation also had national security overtones.[21] In both situations the U.S. government intervened to prevent potential technology transfer to other nations.

The negative implication of foreign direct investment for U.S. national security, therefore, is the potential loss of control over the entire spectrum of the development of selected weapon systems, their components and associated research. This concern is founded on the belief that foreign-owned, domestically based corporations owe their allegiance to their home nations and may somehow be coerced away from cooperating with the United States. There is also concern that technologies and secrets may be repatriated against the wishes of the U.S. government, or that experience gained by foreign corporations producing U.S. weapon systems will be applied offshore.

Investors seeking to acquire or control U.S. defense firms see things quite another way. They argue that their investments support, or in some cases sustain, the U.S. defense industrial base. Particularly in an era when defense spending is declining internationally, consolidating defense companies across national boundaries affords efficiencies in operation, production, and research overhead. Furthermore, there is the real possibility that foreign firms may bring to U.S. weapon system production manufacturing techniques and product technologies that are not available domestically.

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19 Fahim-Nader 1991, 30. Amounts are in nominal dollars.

20 Carlucci 1992, 403–4.

21 Velocci 1993, 26–27.

C. THE IMPLICATIONS OF GLOBALIZATION

The implications for U.S. global interests stemming from changes in the world security environment since 1989 are legion, raising questions crucial to the ability of all countries to adapt and respond to new international challenges. The preceding discussion raises a set of issues regarding the ultimate beneficiaries of dual-use investments: Will the U.S. will be the heir of its public largesse, or will the primary benefits accrue overseas? The experiences of the U.S. consumer electronics, machine tool, automobile, and aerospace industries suggest that what may originate as a strength for U.S. firms may ultimately be exploited more capably by foreign enterprises. We ask, is there anything that can be done by government to prevent this? Should we worry?

There appears to be agreement in the literature on the continued trend toward global economic integration. Opinion diverges over the issue of the appropriate role for government and the structuring of effective public policies to promote U.S. security. Both of these considerations are important for dual-use programs.

For instance, the statutes governing U.S. applied technology programs generally limit participation to U.S. firms and foreign entities that meet reciprocal treatment conditions. With the continued integration of the world's economy and concomitant sharing of technological know-how across borders, within and outside of individual multinational firms, the question arises: How effective are such restrictions on foreign firms in protecting technology and intellectual property? The answer suggested by the writings surveyed is that such protections are probably not very efficient. On the other hand, as OTA points out, there is a tendency for R&D to be done by multinationals in their "home" countries. One can infer, then, that denying foreign firms access to U.S. government programs may protect the U.S. public interest and avoid subsidizing foreign competitors.

One could argue that subsidizing foreign firms is not necessarily bad public policy. It is clear from the various critical technology plans and reports that the United States is no longer in the technological forefront in all areas.[22] Thus, U.S. firms could benefit by encouraging the transfer of technology and know-how from foreign entities. An example of this in action for the TRP is the Bath Iron Works project, where shipbuilding know-how and management techniques are being learned from Kvaerner Masa

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[22] Department of Defense 1989b, 1990, 1991. National Critical Technologies Panel, 1991, 1993.

shipyards in Finland.[23] The Department of Defense itself has several ongoing initiatives that seek to leverage foreign technologies for U.S. benefit. These include the Technology for Technology (TFT) program, which approaches technology exchange with Japan from a barter perspective,[24] and initiatives to secure technologies from the Former Soviet Union.

In a global environment, therefore, the increasing dual-use nature of many commercial technologies coupled with defense industry globalization means that international business relationships and interdependencies increase the ease with which militarily relevant technology becomes available. At the same time, such relationships also increase the foreign content of U.S. weapons systems directly and indirectly.[25] To be successful, dual-use strategies must avail themselves not only of domestic opportunities, but also of the growing stock of new commercial technologies being developed worldwide that have dual-use potential. Particularly in an era of tight defense budgets and the increasing relevance of commercial technologies to the efficient and affordable production of weapons systems, a central tenet of dual-use policy must be to make every effort to support only those activities that promote world-class potential. This should be pursued regardless of the extent to which U.S. and foreign firms are increasingly engaged in cross-border alliances, dependent on foreign sources, or acquired by foreign entities. Such interdependencies will only deepen and broaden in the future as long as permissive trading practices between nations endure.[26]

For commercial industry, the degree to which global distribution of production activities may take place will be a function of telecommunications and transportation to substitute for proximity. There are no a priori reasons to assume that with sufficient

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23 Department of Defense 1995, A12.

24 In this case U.S. commercial or military technologies were to be exchanged for Japanese dual-use technologies.

25 For a discussion of existing evidence of the U.S. military dependence on foreign sources see Hegenbotham et al. 1990.

26 It should also be noted that the increasing globalization of the defense industrial and technology base—the spread of first tier production to less developed countries and newly industrializing countries and the greater integration of second and tertiary tier producers—poses significant challenges to U.S. policy makers. In particular, the United States must not allow itself to become positioned so that it is vulnerable to supply disruptions. Conversely, global interdependencies in trade and defense will tend to reduce the degree to which the United States may pursue the "carrot and stick" approach to international relations. In cases where other nations act in ways that are antithetical to the interests of the United States, potential reactions by allies and adversaries in the context of foreign commercial and military dependencies must be weighed prior to taking action.

resources research, design, development, and production activities cannot be distributed globally, as with the commercial Boeing 777 aircraft, which is being produced through subcontracts to foreign firms, with design integration and final assembly taking place in the United States. Distributed design and production for military aircraft has been amply demonstrated in the cases of several European aircraft, including the Alpha Jet, Jaguar, and Tornado. Even for some equipment in the U.S. inventory, such as the F-16, foreign production of parts and components is a reality.

To provide for national security, it appears that the best course of action for the U.S. military would be to build upon world-class commercial capabilities wherever possible, including activities that offer unique, non-commercially available capabilities as quality multipliers. Hence, while promoting dual-use technology investments, militarily unique investments would also remain indispensable. Commercial capabilities properly leveraged would lead to more affordable military systems, and at the same time would free up budget resources to pursue specific military applications.

D. IMPLICATIONS FOR DUAL-USE PROGRAMS

Close government-industry collaboration in other countries is more integral to political and societal traditions than it is in the United States. Consequently, dual-use investment, or the use of government funds to pursue goals that offer both commercial and military benefits, is not ideologically contentious in those countries. Instead, government subsidies in such countries might depend on the geopolitical location that a firm—particularly an MNE—chooses. As the development, design, and production of arms become less geographically constrained through improved connectivity, the situation of vital military industrial and technology base capabilities will increasingly become a business consideration akin to that in the commercial sector.

Given the considerable lead that some commercial technologies have over their military counterparts, and the apparent competitive advantage that firms accrue by geographically locating their R&D operations where significant concentrations of similar activities already exist, the U.S. is no longer assured that its military needs will be met from domestic sources. Combined with the likelihood that defense firms will begin to act more like their commercial counterparts in the post-Cold War environment, U.S. dual-use investments may have to be made abroad as well as domestically to take advantage of cutting-edge technologies, products, and processes.

E. SUMMARY

- The United States no longer stands head and shoulders above its allies in terms of technological sophistication or economic competitiveness. *We are now in the long run.* That is, henceforth the U.S. will compete on a relatively even footing with other advanced nations, and the outcome of this competition will be a function of this nation's ability to adapt to and correctly anticipate a rapidly changing world.
- Government-industry cooperation after W.W.II was not alien to Japanese economic culture; in fact, it fit easily within the emerging post-war system of kiretsu—strategic business alliances between firms involving production, finance, labor, and marketing. In fact, the effect of the kiretsu system appears to have been at least as successful in marshaling and employing resources as the pre-war zaibatsu—large, *integrated* corporations that embodied all of the functions of production, finance, labor and marketing.
- Government-industry cooperation in Europe has paralleled the Japanese experience more so than that of the United States. Investments in research and development are heavily weighted toward commercial developments rather than defense, and they largely reflect the greater integration of commercial lines of business with defense production activities.
- The close collaboration of MNEs and defense firms for the purposes of developing militarily relevant technologies may adversely affect U.S. national security where cross-border collaborative activities are involved.
- Cross-border collaborative business relationships represent different types of foreign influences, stemming from those that may be voluntarily encouraged to those that are coerced. The degree to which such relationships may adversely affect national security depends on the nature of the cross-border relationship, the availability of alternative domestic capabilities, and whether or not foreign firms are acting openly.
- Foreign sourcing offers potential advantages and disadvantages for U.S. security. On the one hand it offers access to a broader range of potentially dual-use technologies, many times at a fraction of the cost of developing them domestically. On the other hand foreign sourcing leads to an erosion of U.S. technological capabilities by limiting our experience with the development of these technologies.
- Cross-border alliances are a double-edged fact of life in the commercial world. When U.S. firms establish qualified production facilities in other nations, they allow more intensive technology transfer activities than occur through foreign sourcing. As such, these alliances could be viewed as a

considerable threat to national security since both classified and proprietary information is made available to other nations, and there are the ever-present risks of intentional transfer of knowledge to potential U.S. adversaries. Advantages from such activities should not be ignored, however: foreign markets may become amenable to the purchase of U.S. weapons systems; system interoperability worldwide with allied nations is promoted; foreign qualified suppliers may become a source for the U.S. military in times of extreme national emergency; and, foreign world-class technology becomes available for U.S. firms.

- Foreign direct investment also has its pluses and minuses for U.S. security. The negative implication of foreign direct investment for U.S. national security is the potential loss of control over the entire spectrum of the development of selected weapon systems, their components, and associated research and development. There is also concern that technologies and secrets may be repatriated against the wishes of the U.S. government, or that foreign corporations producing U.S. weapon systems will gain experience that will be applied offshore. Conversely, foreign investments support, or in some cases sustain, the U.S. defense industrial base, and there is the real possibility that foreign firms may bring to U.S. weapon system production manufacturing techniques and product technologies that are not available domestically.

- Most discussions of competitiveness and national security in a global economy revolve around the issue of how to promote the "national interest." In turn, national interest is regarded as improving the welfare and security for a particular geopolity. In a capitalist, free-trade system, the location of firms and their productive activities determine welfare, not abstract notions about the competitiveness of the nation-state itself.

- Ultimately, to provide for national security in a global economy the U.S. military must build upon world-class commercial capabilities wherever possible. It must also pursue activities that offer unique, non-commercially available capabilities as quality multipliers. Commercial capabilities thus leveraged will lead to more affordable military systems, and at the same time free up budget resources to pursue specific military applications.

- MNEs face different risk/reward combinations as a function of venue; depending upon its choice of geopolitical location a firm may be able to attract government subsidies. As the development, design, and production of arms become less geographically constrained through improved connectivity, the situation of vital military industrial and technology base capabilities will increasingly become a business consideration akin to that in the commercial sector. Given the considerable lead that some commercial technologies have over their military counterparts, and the apparent competitive advantage that firms accrue by geographically locating their R&D operations where significant concentrations of similar activities already exist, the United States is no longer assured that its military needs will be met from domestic sources. U.S. dual-use investments may have to be made abroad as well as domestically to take advantage of cutting-edge technologies, products, and processes.

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VI. FOREIGN EXAMPLES OF DUAL-USE

As noted in the preceding chapter, the experience of other nations in the dual-use arena differs considerably from that of the United States. Foreign governments tend to view their national interests from a more unified perspective, considering economic and military security one and the same. As a result, government technology and industry assistance programs blend both commercial and military goals whenever possible—adherence to the notion that there is a need to separate the interests of the public and private sectors is, at best, "foreign."

This chapter illustrates the pursuit of dual-use goals via considerable integration of military and commercial industrial bases in East Asia, Europe, and non-U.S. America. It provides several specific examples: the Japan-U.S. FS-X cooperative fighter development program and a close look at the co-cured composite wing box developed for that program; China's efforts to modernize its aviation industry; Vickers' unsuccessful efforts to transition tank technology into crawler tractor products; and Embrarer Aircraft's resounding success in producing products suited to both commercial and military customers. These examples include elements of technology spin-off and spin-on, particularly efforts to integrate military and commercial capabilities.

While at the end of each section we relate the implications of the cases studied to the four programmatic approaches for dual-use introduced in Chapter 2, it is important for the reader to note that unlike dual-use programs in the U.S., foreign activities generally represent a blend of two or more models. In particular, the much closer relationship between government and industry in other countries fosters an atmosphere in which industrial base strengthening tends to underlie all dual-use activities, including those examined here.

A. JAPANESE AVIATION

Military technology investments are often used as a cover for commercial industrial policies, a practice that certainly figures in the debate between Democrats and Republicans over the use of DoD applied technology monies. In Japan, military investments in new aerospace technologies offer a convenient, but transparent, smoke screen for obtaining U.S. aerospace technologies initially for military purposes, but ultimately as part of a strategy to use these same technologies to promote a domestic aerospace industry. The FS-X to a greater degree, and the co-cured composite wing to lesser degree, are cases of such a strategy at work.

1. FS-X

The FS-X is a new ground-support fighter being developed by Japan in cooperation with the United States. This program represents a giant advance toward the goal of developing a completely indigenous Japanese fighter. This achievement reflects years of purposeful government-supported aircraft development as well as the growth of a sophisticated national industrial base able to provide the requisite technologies. It also rests on years of technology transfer through the licensed production of foreign military aircraft and subcontracting work on foreign commercial airliners. Much of the experience and know-how gained on the FS-X program can and will be applied commercially.[1]

a. Japan's Aircraft Industry

Japan's aircraft industry is substantially integrated, with the same companies producing both military and commercial products, often in the same plant. The principal companies are Mitsubishi Heavy Industries (MHI), Kawasaki Heavy Industries (KHI), and Fuji Heavy Industries (FHI). Total industry output is small by U.S. standards, less than $7 billion in 1991, with military demand accounting for 75 percent of this amount.[2] A segregated commercial segment would thus be impractical.

The Ministry for International Trade and Industry (MITI) has played a key role in developing Japan's national aircraft industry. Importantly, MITI's Bureau of Aircraft and Ordnance has oversight over the production of all aircraft and parts, military and commercial.[3] Further, the 1958 Aircraft Promotion Law explicitly linked the goals of developing military and commercial aircraft industries.

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1 This discussion of the FS-X program draws heavily on Green 1995, Lorell 1995, and U.S. General Accounting Office 1995a.

2 See the table in Wilkins et al. 1994, 202.

3 MITI's position is confirmed in the Law for Enterprises Manufacturing Aircraft. See U.S. Congress 1995, 22. Amazingly, the Bureau of Aircraft and Ordnance is reported to employ only 12 people. See Wilkins et al. 1994, 200.

Development of Japan's aircraft industry has proceeded along several tracks. One was the production under license of foreign-designed military aircraft. With MITI's help in 1955, MHI began production of North American's F-86F fighter and KHI built Lockheed's T-33A trainer. In subsequent years, Japanese companies license-produced Lockheed's F-104J Starfighter as well as McDonnell-Douglas' F-4EJ Phantom and F-15J Eagle. Japanese industry benefited greatly from licensed production, gaining both technology and experience.

Parallel to licensed production, the Japanese companies developed and produced indigenous fighter aircraft for the Japan Defense Agency (JDA). An early project was the FHI T-1 jet trainer, which resembled the F-86F and first flew in 1958. Its initial British engine was eventually replaced by one developed by Ishikawajima Harima Heavy Industries (IHI). In 1966, work began on the supersonic T-2 jet trainer, which resembles the Jaguar aircraft developed in Europe. In 1970, MHI began work on the F-1 fighter, integrating weapon systems and (mainly imported) military avionics into the T-2 airframe. The integration experience gained was invaluable although the F-1 itself was not a particularly good fighter.[4] In 1981 KHI began work on the subsonic T-4 trainer, an indigenously developed jet using an IHI-developed XF-3-30 turbofan engine. This program utilized computer-aided design and manufacturing techniques and incorporated several new avionics subsystems. Its flight in 1985 suggested Japanese industry was ready to develop an indigenous fighter.[5]

A third track was the development of transport aircraft, often aimed at commercial markets. The 1958 Aircraft Promotion Law funded a consortium of the leading producers to develop a medium commercial transport. The government funded over half the R&D costs for the resulting twin turboprop YS-11, which first flew in 1962. Some 200 were produced but foreign sales were disappointing. In 1966, the YS-11 consortium began development of the C-1 military medium jet transport. While this effort provided further valuable experience, only 40 were produced and the military instead purchased Lockheed's C-130 Hercules transports. MITI thereafter encouraged the industry to build subcontractor relationships with U.S. airliner manufacturers. MITI led a consortium in

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4 The F-1 reportedly performed poorly and was spurned by pilots. See Tolchin 1992, 78. The F-1 has been characterized as slow and difficult to fly, with an inadequate payload. See Lorell 1995, 61.

5 This point is made by Lorell 1995, 84. The JDA's Technical Research and Development Institute (TRDI) announced in 1985 that Japan was capable of developing a fighter indigenously except for the engine. See U.S. General Accounting Office 1995a, 9.

1973 to build a joint design and development relationship with Boeing, leading to Japanese participation on Boeing's 767 airliner program. Japan's level of participation increased further in a subsequent but abortive 7J7 development and on the current 777 program.

b. Program Background

The Japanese intended to develop the FS-X indigenously but agreed in 1987, under heavy US pressure, to establish a cooperative program based on modifying the U.S. F-16 fighter. A government-level agreement was signed in November 1988, but President Bush was forced to renegotiate it in 1989 because of congressional fears that the United States was giving away technology without adequate compensation. Further disputes delayed an agreement between MHI and the F-16 producer, General Dynamics (now Lockheed), until February 21, 1990. While development costs have escalated substantially, the program has moved ahead and the first FS-X prototype flight in October 1995 was reportedly successful.[6] A production agreement for the FS-X has not yet been negotiated.

The Department of Defense (DoD) pushed U.S. involvement in the FS-X program, in part, to delay the growth of Japan's indigenous fighter development capability.[7] An independent capability could reduce U.S. leverage and weaken the U.S. defense industry, particularly if Japan lifted its ban on exporting weapons.[8] Such a capability could also be destabilizing in East Asia, encouraging an arms race among Japan's wary neighbors. However, by inducing the Japanese instead to modify an F-16, the U.S. hoped to delay Japan's emergence as a developer of world-class fighters. Congressional critics, on the other hand, feared that the transfer of F-16 technology would help Japan develop its commercial aircraft industry, eventually damaging commercial airliner manufacturers in the United States. The critics forced a renegotiation of the agreement that angered the Japanese, limited the transfer of F-16 technology, and spelled out the Japanese technology and economic benefits the U.S. would receive in return.

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6 The test pilot characterized the handling characteristics of the FS-X as smooth. See *Aviation Week & Space Technology*, 16 October 1995, 22.

7 See the discussion in Lorell 1995, 107, 173, 373–75.

8 Japan's ban on exporting military products has strong popular sanction but, legally, is based on a 1976 cabinet policy decision. At some point, in order to reduce costs by increasing the scale of production, Japanese industry might succeed in overturning this policy. See Lorell 1995, 18, 409.

The F-16 data transferred by the U.S. included design data, which was not transferred to other foreign countries that produced the F-16 or F-16 parts under license. However, the U.S. held back critical technologies related especially to the software enabling the F-16's fly-by-wire capability, the "hot" section of the General Electric (GE) engine, and stealth capabilities. The Japanese were required to transfer to the United States any technological developments essentially derived from the transferred F-16 data and make other FS-X technologies available for purchase. Further, Japan agreed to contract with U.S. firms for at least 40 percent of the budgeted development work and 40 percent of the value of future production. U.S. firms will receive over $1 billion during the development phase alone.

In practice, the FS-X program greatly resembles the indigenous program the Japanese originally envisioned. The Japanese government and MHI, the prime contractor, control decisions on design configuration. They have substantially modified the F-16 airframe and developed mostly new, indigenous subsystems. They have applied their own fire control radar, mission computer, fly-by-wire flight control system, stealth materials, and advanced composite wing technology. To a large degree, U.S. subcontractors have been used only to supply components for the FS-X prototypes that remain unchanged from their configurations in the F-16.[9] New design work has been assigned mainly to Japanese engineers. Lockheed, however, has been allowed to produce eight left-side wings using the Japanese co-cure technology and will design and produce certain airframe components and avionics equipment.

c. Dual-Use Technologies

Japan's military aircraft industry has gained a great deal from the FS-X program. Most important is the experience of developing and integrating a world-class fighter. They have achieved largely indigenous development in most areas, the main exception being the engine. The main U.S. contribution was to provide the F-16 as a design baseline. This reduced development costs yet permitted development of a substantially different airframe.[10] U.S. involvement also gave the FS-X program political cover in the

9 See the discussion of work allocation in U.S. General Accounting Office 1995a, 46, 48.

10 In 1989, JDA estimated that using the F-16 as a baseline would reduce development costs by 25 percent compared with the cost of completely indigenous development (Lorell 1995, 296). A U.S. study found that the transfer of F-16 technology enabled the Japanese to avoid a considerable investment (U.S. General Accounting Office, 1995a, 8). These savings were offset, to some extent, by

face of declining procurement budgets. In the end, the program gave Japan valuable skills that will support future aircraft development, both military and commercial.

The principal gain is experience at systems integration. MHI in particular has built an experienced team of engineers that is wrestling with and solving the demanding task of integrating complex electronic and other systems so that they function properly and support one another. This is an area in which the Japanese were thought to be weak. This experience will be directly relevant to the next fighter development program. Further, while the FS-X carries many uniquely military systems, much of the integrating skill should carry over to future commercial developments.[11]

The Japanese industry gained valuable experience by substantially redesigning the F-16 airframe. The transfer of detailed F-16 design data provided a baseline and may have given the Japanese insights into fighter design practices.[12] However, while this deepening of Japan's design know-how may have general commercial benefits, specific FS-X design solutions will not have much commercial application.[13] Fighter designs are fundamentally different from transport designs, for example, to accommodate much greater stresses. Fighters are optimized for performance while commercial transports aim much more at economical operation.

The FS-X incorporates Japanese-developed fly-by-wire flight control. With this technology, a computer "flies" the aircraft by translating the pilot's actions into precise instructions for instantaneous changes in flight control surfaces. Among other benefits, this capability permits a less stable, more maneuverable airframe design. The Japanese gained fly-by-wire experience in the early 1980s through a JDA-funded demonstrator program using a modified T-2 trainer. With further experience developing the FS-X fly-

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the cost of transferring FS-X technology to the U.S., e.g., duplicate tooling for wing production at General Dynamics.

11 This judgment is expressed, for example, in U.S. General Accounting Office 1995a, 7, 44.

12 The latter point is debatable since technical data may not reveal why particular decisions were made. See Lorell 1995, 56, 209.

13 FS-X experience may have commercial relevance at the general level of development practices. Boeing, for example, is now applying lessons learned on its commercial 777 airliner program to U.S. fighter programs. This includes application of a computer-aided theodolite system, pioneered on the 777 program, to align major subassemblies for the F-22 fighter. Also, for the Joint Advanced Strike Technology (JAST) competition, Boeing is applying its 777 experience using integrated product development teams supported by upgraded CATIA three-dimensional design data base systems. See *Aviation Week & Space Technology*, 24 July 1995, 48, and 25 September 1995, 53.

by-wire system, Japan has achieved competence in a key technology needed for world-class fighters.[14] Moreover, fly-by-wire systems were introduced for commercial transports by Airbus and now by Boeing on its 777 airliner.[15] Japan's fly-by-wire experience is thus an important enabler for a future commercial airliner program.

Mitsubishi Electric Company (MELCO) has developed an active phased-array (APA) fire control radar system for the FS-X. The APA radar utilizes hundreds of transmit/receive (T/R) modules to scan for targets electronically, which is much faster than the conventional approach of mechanically rotating the radar antenna.[16] APA speed and flexibility give the radar potential advantages in tracking multiple targets, interleaving radar functions, resisting hostile jamming, and minimizing the aircraft's own radar signature. MELCO has been developing APA radar prototypes for JDA since 1964 and initiated flight testing in 1986.[17] The JDA-funded effort benefited greatly from MELCO's commercial experience producing the gallium arsenide monolithic microwave integrated circuit (MMIC) chips used in the T/R modules.[18] In turn, MELCO's experience developing MMIC chips and T/R modules for the FS-X may support new commercial applications, for example, in air traffic control, satellite and mobile communications, and automotive collision avoidance and cruise control devices. Further, the

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14 The F-16, F-18, and the future F-22 and JAST aircraft all utilize fly-by-wire flight control. The F-16 technology was not transferred under the FS-X program, in part, because the U.S. believed it would strengthen Japan's commercial aircraft capabilities. See U.S. General Accounting Office 1995a, 16.

15 Boeing's fly-by-wire systems for the F-22 and JAST programs are being thoroughly tested in a special avionics laboratory and on flying testbeds, so that problems can be corrected prior to prototype flights. Boeing gained experience with this approach in its earlier 777 airliner program. See *Aviation Week & Space Technology*, 25 September 1995, 53, and 6 November 1995, 24.

16 APA radars are discussed in detail in Chang 1994.

17 See Chang 1994, 37, 77. MELCO also produced conventional U.S. radars under license, including the Westinghouse APQ-120 for the F-4EJ beginning in 1971 and the Hughes Aircraft APG-53 for the F-15J beginning in 1981. See Alexander 1993, 41.

18 The MMIC chips are based on gallium arsenide rather than silicon, improving performance but also raising costs and manufacturing difficulties. MELCO began producing discrete gallium arsenide devices in the late 1970s for use in televisions, video cassette recorders, and laser devices for compact disc players. MELCO now produces the highly integrated MMIC chips, serving commercial markets for cellular telephones and direct broadcast satellite receivers and using the same production lines for military chips. MELCO utilizes flexible automated processes and has developed custom equipment for assembling commercial modules. Japan dominates the production food chain, including the starter gallium arsenide wafers and slugs as well as key production equipment, supporting military production in both Japan and the U.S. See Chang 1994, 64–75.

FS-X will be the first fighter to be equipped with an APA radar, making Japan a player in a technology that will be essential for future world class fighters.[19]

The Japanese companies have applied advanced composites technology to FS-X structures, including a co-cured composite wing box. This is an important capability for modern fighters, a capability that has been developed in the U.S. for the F-18E/F and F-22 fighters. It is also an important structural technology for new commercial airliners. The evolution of this technology in Japan is discussed in detail in a separate section below.

d. Future Developments

The future of the FS-X program itself is in some doubt. A production agreement must yet be negotiated between Japan and the United States, and that process may prove difficult since it involves allocation of work shares. Recent reductions in Japan's defense procurement budgets may also place the program in jeopardy, reducing the previously planned buy of 130 aircraft.[20] Japan, nevertheless, has already gained invaluable development experience and is now planning indigenous development of a world-class FI-X advanced stealth fighter that may challenge the F-22 for markets in the future.[21] JDA has begun funding IHI to develop a turbofan engine for the FI-X. A FI-X technology demonstrator, if funded, could be flying by 2007. On the commercial side, MITI is supporting consortia to develop a YS-X regional (100-seat) airliner and its engine.[22] Industry is also advocating development of a military transport to replace the C-130, which is deemed inadequate for deploying United Nations peacekeeping forces to distant trouble spots.

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19 The FS-X radar will be the first fire control radar Japan has fielded. Its design is relatively conservative so that it does not outperform the current conventional F-16 radar and is much less capable than the APA radar being developed for the F-22. See Chang 1994, 29–30.

20 Speculation has placed eventual production as low as 50 aircraft (U.S. General Accounting Office 1995a, 5). The JDA is now requesting a possibly padded total of 141 FS-X, with funding for the first 12 likely in the FY96 budget. See *Aviation Week & Space Technology*, September 18, 1995, 25.

21 See Lorell 1995, 385–86.

22 MITI recently announced that launching the YS-X development program will be postponed indefinitely, although MITI will continue to fund related research and Boeing will continue to work with the Japanese consortium. The high value of the yen and potential competition from a Chinese-Korean regional jet have cast doubt on the commercial feasibility of Japan's YS-X effort. See *Aviation Week & Space Technology*, 18 September 1995, 30.

e. Dual-Use Observations

Japan's FS-X development illustrates a blend of dual-use approaches through the integration of national research and manufacturing technology bases with industrial base strengthening an important goal. The integrated aircraft manufacturers built their capabilities through licensed production of foreign military aircraft together with government-sponsored indigenous development of fighters and an unsuccessful commercial airliner. This work enabled them to produce and eventually co-develop parts for foreign airliner manufacturers through purposeful spin-off. This subcontracting work also led to technology transfers and experience useful for the FS-X development through concerted efforts at direct spin-on. Other technologies needed for the FS-X were developed based on years of targeted research funded by the Japan Defense Agency (JDA) as well as company- and government-funded research in Japan's advanced electronics, materials, and other supporting industries—indirect spin-on. The experience gained through the FS-X, in turn, will provide capabilities and technologies useful for future military and commercial aircraft, electronics, and materials markets.

2. Co-cured Composite Wing

The FS-X utilizes a composite wing box jointly developed by MHI and FHI. Among other advantages, a composite wing can reduce weight relative to a conventional metal wing. Of particular note, the wing will be formed by co-curing, a heat and pressure curing process to join the complex internal wing structure to the lower wing skin. This approach avoids the cost and weight of joining the many parts by means of conventional metal fasteners. In the early 1980s, only the McDonnell Douglas AV-8B utilized an all-composite wing, but its many composite parts were joined by conventional means.[23]

Japan's FS-X composite wing experience places it in a strong position for developing future indigenous fighters. For example, two current U.S. fighter development programs, the F-18E/F and the F-22, both utilize composite wings. Japan's know-how will also prove useful for commercial aircraft structures. FHI, which jointly developed the FS-X wing with MHI, claims already to have applied the co-cure technology to the

23 See Lorell 1995, 93. The AV-8B used a co-curing process similar to the Japanese FS-X approach for its horizontal stabilizer.

horizontal stabilizer jointly developed with Boeing for the 777 airliner.[24] The technology would also be used extensively on Japan's proposed YS-X regional airliner.[25]

a. Technology Development

The Japanese companies developed the capability to manufacture co-cured composite structures by participating in a variety of development and manufacturing projects over the years.[26] These included indigenous government-funded programs, production of licensed foreign military aircraft, and subcontracting to foreign commercial manufacturers. The key was to gain experience and transfer available technology.

In the 1960s, Japan developed a strong position in the application of composites technology to sporting goods. The textile company Toray became a world leader in the carbon fibers used for many composite products. While aircraft structures require much more advanced material properties than sporting goods, the latter market helps support a common supply infrastructure that aircraft manufacturers can utilize.[27]

Thus, companies such as Toray and Mitsubishi Rayon were available to work with MHI in 1974 when the JDA funded the development and flight testing of a composite landing gear door for the T-2 jet trainer. Also in 1974, the JDA funded KHI's development and flight testing of a composite ground spoiler for the C-1 military transport. The JDA subsequently funded MHI's development of a composite vertical canard for the T-2 (1978) as well as production for the T-4 trainer of MHI's composite speed brake (1982) and KHI's composite aileron, rudder, and nose landing gear door. In 1981, the JDA initiated a project with MHI to develop a co-cured composite wing box for a proposed indigenous fighter.

The Japanese companies also gained experience through civilian programs funded by the government. For example, in 1978 the National Aerospace Laboratory (NAL)

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24 See Wilkins et al. 1994, 176–77. However, the composite tail will be produced by Boeing rather than FHI. See Lorell 1995, 92.

25 See U.S. General Accounting Office 1995a, 44.

26 The discussion of Japanese experience is based primarily on Lorell 1995, 88–94, and Wilkins et al. 1994, 4–6.

27 For the structural applications considered in this discussion, reinforcing fibers must have particularly high tensile strength and/or stiffness. Matrix resins must also have special properties for environmental resistance and perhaps high-temperature strength. Manufacturing quality must be high to preclude cracks and other flaws.

funded a project to modify a KHI C-1 transport to explore short take-off and landing (STOL) concepts. Under this effort, MHI developed a large (36-foot) co-cured composite tail. In addition, MHI produced composite parts for National Space Development Agency (NASDA) rockets, including the N-II (1979), the H-I (1986), and the H-II (1987).

Licensed production of foreign military aircraft gave the Japanese early experience in the production of composite parts. In 1980, MHI began to produce the composite horizontal stabilizer and speed brake for the F-15J, which was produced under license from McDonnell Douglas. The F-15 was the first fighter aircraft to make extensive structural use of composites. At Japanese insistence and over U.S. Air Force objections, the U.S. agreed to transfer the F-15's composites technology, enabling the Japanese to produce the boron/epoxy parts and gain valuable processing and bonding experience. KHI also produced composite parts for the F-15, including the vertical fin torque box and rudder. KHI earlier had produced some composite parts for the F-4EJ, also produced under license. Interestingly, the F-16 used as a baseline for the FS-X included relatively few composite structures.

Among the most important contributors to Japanese capability is the subcontracting work performed for the commercial divisions of Boeing and McDonnell Douglas. This work provided both experience and invaluable technology transfer. The Japanese manufacturers participated in Boeing's 767 airliner program, beg n in 1978. Japanese engineers were involved in the development of advanced composite structures for the 767 and Boeing helped transfer the associated manufacturing processes to Japan. This enabled a major increase in the capability to manufacture composite structures, especially for KHI and FHI, and may have contributed to indigenous programs such as the MHI/NAS STOL project mentioned above, which also began in 1978.[28] On the other hand, earlier work funded by the JDA helped MHI and KHI gain sufficient competence to participate in the 767 effort.

In 1984, Boeing initiated a 7J7 airliner project, responding to Japanese demands for greater involvement in airliner development. The Japanese convinced Boeing to let them develop a composite tail for the 7J7. Boeing helped 50 Japanese engineers transfer the requisite Boeing composites technology and, in 1985, MHI and FHI began joint development of the composite horizontal stabilizer torque box. Although Boeing eventually canceled the 7J7 project, the Japanese nevertheless gained valuable experience

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28 See Lorell 1995, 90–91.

and technology. The Japanese later participated extensively in the development and production of Boeing's new 777 airliner, although Boeing did not agree to let them produce the co-cured composite tail.[29]

The FS-X composite wing box was developed by MHI and FHI. MHI developed the co-cured internal structure and lower wing skin, using composite materials tailored by Mitsubishi Rayon Corporation and expensive invar steel tooling.[30] FHI developed the upper wing skin, using composite materials developed by Toray. The upper skin was attached to the co-cured assembly by conventional metal fasteners. Use of co-curing reportedly reduced the weight of the wing by one third.[31] The wing technology was transferred to General Dynamics, which made four left wings with technical assistance from Japanese engineers.[32] However, General Dynamics did not participate greatly in designing the wing. The commercial relevance of Japan's co-cure experience on the FS-X is readily illustrated by the use of co-curing for a composite rudder on the Airbus A320 and for the horizontal stabilizer on Boeing's 777.

b. Industrial Integration

This discussion of Japanese preparation for developing the FS-X co-cured composite wing illustrates the substantial integration of the military and commercial aircraft industries. It is apparent that the technology and experience gained on one side has contributed importantly to the capabilities of the other side. There is evidently also substantial integration of production facilities. Military and civilian assembly lines are often housed side by side, with workers shifted between the lines.[33] MHI, for example, houses both military and civilian production at its Nagoya plant. Further, MHI has acquired sophisticated composites production equipment for the FS-X program, including

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29 Other commercial composites subcontracting included KHI's production of a flap hinge fairing (1985) for McDonnell Douglas' MD-80 and a 747 outboard flap (1985) for Boeing. MHI produced the wing trailing edge for the MD-80 (1983) and the inboard T/E flap for the 747 (1986).

30 FS-X wing development is discussed in Lorell 1995, 321-5.

31 See *Aviation Week & Space Technology*, January 23, 1995, 33. Lockheed (previously General Dynamics) viewed the co-cure technology as unique but not better than U.S. composites technology.

32 MHI was reluctant to transfer the technology, claiming much of it was based on company-funded commercial programs. JDA was forced to pay MHI for the technology transferred to General Dynamics. General Dynamics itself was not viewed as a leader in airframe composites technology and reportedly experienced considerable difficulty engineering composite structures for the abortive A-12 program. See Lorell 1995, 165, 195–96, 273, 292.

33 See U.S. General Accounting Office 1994, 7.

tape-laying equipment, contour measuring machinery, and test facilities. This equipment will be available for other projects in the future.

c. Dual-Use Observations

As with the overall development of the FS-X, the development of the co-cured composite wing for the FS-X also exemplifies dual-use via industrial base strengtheing within a component of the Janapense aircraft industry. Aircraft manufacturers gained experience manufacturing composites through JDA-funded research and licensed production of military aircraft. That know-how qualified them to make composite parts for foreign airliner manufacturers, another case of purposeful spin-off, from whom they gained more advanced composites technology that proved useful through direct spin-on in developing the FS-X wing. In turn, their FS-X experience enhances their capability to make composite structures for future commercial airliners, a purposeful spin-off of a direct spin-on. At the same time, years of government-supported research on composites helped Japanese companies develop markets for composite sporting goods and other products, enabling aircraft manufacturers to draw on a strong infrastructure of composite materials and equipment suppliers—which may be taken as both part of industrial base strengthening and indirect spin-on activities.

B. MODERNIZATION OF CHINA'S AVIATION INDUSTRY

China began the 1980s with a large military aviation industry that produced as many as 450 fighters per year and supported a force of almost 5,000 fixed-wing combat aircraft.[34] Its commercial aviation industry, however, did not produce modern aircraft, and the obsolete aircraft that it did provide were of poor quality.[35] China has since begun a serious effort to modernize both its aircraft and its manufacturing capability. It has taken direct steps to develop new fighters and acquire foreign military technology. It has also pursued the long-term development of a modern, national aviation industry serving both military and commercial markets. Foreign commercial manufacturers have made a

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34 See Allen et al. 1995, 162–63.

35 The Chinese have a history of poor quality control, ranging from F-6 fighters the military would not accept in the 1950s to F-7s observed at the Chengdu Aircraft Corporation in 1989 with "rough lap joints" and "occasional coarse rivet finishing" (Bitzinger 1991, 14–15). In 1975, poor manufacturing quality reportedly forced China to overhaul its entire fleet of A-5s (Allen et al. 1995, 76).

key contribution to this endeavor by improving commercial capabilities at companies that also make military aircraft.

1. Military Aircraft

The Soviets helped China establish its aircraft industry in the 1950s, and most of China's current combat aircraft are based on Soviet designs from that period. In 1956, China began licensed production of the F-5, based on the MiG-17, using Soviet components. At the time of the China-Soviet split in 1960, China was in the early stages of licensed production of the F-6, based on the MiG-19. The loss of Soviet advisers and aid delayed series production of the F-6 until 1963.[36] Subsequent fighters had to be developed or reverse-engineered without Soviet assistance, causing great difficulty for Chinese industry. For example, the A-5 ground attack aircraft was a modified version of the F-6 that required 11 years to bring into production in 1969.[37] Similarly, in 1961 China initiated development of the F-7, based on the MiG-21, but was forced to reverse-engineer the design based on early Soviet deliveries and subsequent samples pilfered from Vietnam-bound Soviet shipments. While production began in 1967, output was limited to a total of 100 aircraft until technical problems could be corrected in 1979.[38] Finally, in 1964 China launched its F-8 program, a challenging indigenous development of a twin-engined high-altitude interceptor using a MiG-21 baseline. The F-8 flew in 1969 but was not validated for production until 1979 and was still considered an operational test aircraft in 1989.[39] China has thus had experience producing and developing fighter aircraft, but its capabilities remain years behind those of the world leaders.

China is especially weak at developing the avionics, weapons, and engines critical to fighter performance. While the Chinese do produce these items, they have made a concerted effort since the 1980s to acquire superior foreign technology. However, because imported subsystems are expensive, they are used primarily to upgrade aircraft

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36 The F-6 continued in production until 1986 and still accounted for almost two-thirds of China's fighter inventory in 1994. See Allen et al. 1995, 163, 222–23.

37 See Allen et al. 1995, 225. As noted above, the entire fleet was recalled for overhaul in 1975. Problems with the A-5, in part, reflect the turmoil caused by the Cultural Revolution in China during this period.

38 By 1994, China had 586 F-7s. See Allen et al. 1995, 163, 223.

39 China had 205 F-8s in 1994. For discussion of the F-8, see Allen et al. 1995, 76, 150–51, 163, 225. Note that even with upgraded subsystems, the F-8 is considered obsolete. See Bitzinger 1991, 26.

for export markets rather than to improve the capabilities of the People's Liberation Army Air Force (PLAAF).[40] The F-7M, for example, is equipped with British avionics systems from GEC, including fire control radar and a computer-linked head-up display to aim weapons, but most F-7Ms are exported.[41] Similarly, an A-5M export model was developed in collaboration with Aeritalia, using the radar, head-up display, and other avionics from the Italian-Brazilian AMX attack aircraft program, reportedly entering production in 1990.[42] Such programs help China's aviation industry become familiar with foreign capabilities and provide valuable integration assistance and experience, useful for improving domestic subsystems.

Prior to the Tiananmen Square bloodshed in June 1989, the U.S. also engaged in upgrade programs with Chinese industry. Grumman, for example, contracted to assist the China-Pakistan development of a Super 7 export version of the F-7.[43] The Super 7 might have used the GE404 engine, Westinghouse AN/APG-66 fire control radar, and other U.S. avionics items. After Tiananmen, however, U.S. sanctions forced cancellation of the contract. China nevertheless continued the program, now designated the FC-1 and relying on Russian help. The FC-1 will use the RD-93 improved-thrust turbofan engine developed for Russia's MiG-29.[44] The Tiananmen incident also led China to cancel the Peace Pearl program to upgrade the F-8 with U.S. avionics. Under that program, Grumman had received a $500 million foreign military sales (FMS) contract for technical assistance and kits to equip 50 F-8s with Westinghouse AN/APG-66 radars, Litton LN-39

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40 Between 1980 and 1991, China exported 946 aircraft to third world countries such as Pakistan, Iran, Egypt, and Bangladesh (Bitzinger 1991, 5–7). Exports included 498 F-7s, 227 F-6s, and 206 A-5s. While China sells obsolete aircraft primarily on the basis of low price, it must nevertheless provide upgraded subsystems in order to remain competitive. The PLAAF, however, can afford very few imported subsystems for their aircraft since China's aviation industry demands reimbursement in hard currency for such items (Allen et al. 1995, 142, 224).

41 GEC provided avionics kits for this collaborative export program, even after the Tiananmen incident. See Bitzinger 1991, 11, 30–31.

42 See Bitzinger 1991, 22.

43 See Allen et al. 1995, 224.

44 Russia and Pakistan will both supply components for the FC-1 in this joint development of a multi-role fighter to approximate the performance of Lockheed's F-16. FC-1s exported to Pakistan will probably be equipped with Western avionics while those used by the PLAAF may have Chinese avionics. See *Aviation Week & Space Technology*, June 19, 1995,77. Other reports suggest that the FC-1 will use the Al-31F engine from the Su-27 and GEC or Italian avionics (Allen et al. 1995, 148–151, 224).

inertial navigation systems, head-up displays, and other U.S. avionics.[45] The F-8-2 upgrade program continued using indigenous avionics after China canceled Peace Pearl in May 1990.

In a temporary departure from its policy of industrial self-reliance, China agreed in 1991 to purchase 26 Su-27s from the Soviets.[46] This long-range multirole fighter is said to approximate the performance of the U.S. F-15E and could give China a capability for striking targets, for example, in the South China Sea. Negotiations over the purchase of a second batch of 24 Su-27s have been slowing owing, in part, to China's insistence on technology transfer and production rights. In May 1995, Russia and China reportedly reached agreement on the second sale and, in principle, on licensed Su-27 production at Shenyang. However, the Su-27 is much more complex than the aircraft China produces now and it could take more than 10 years for China to achieve truly indigenous production.[47] China has also negotiated for the purchase of Russian MiG-31s, including licensed production with Russian assistance.[48]

New fighter programs include the multirole F-10 being developed with design and manufacturing assistance by Israel Aircraft Industries (IAI). The F-10 airframe is said to resemble both the F-16 and the delta-shaped wings and canard of Israel's abortive Lavi fighter. Radar and avionics technologies might be based on IAI's upgrade package for the Northrop F-5. The Chinese reportedly hope to use the Al-31F engine from the Su-27,

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45 Possible use of the GE404 engine was also discussed. Original plans had called for Grumman to refit the first two F-8s in the U.S., with test flights at Edwards Air Force Base. See Foreign Technology Division 1991, 4, and Allen et al. 1995, 151, 226.

46 The agreement included the fighters as well as armament, missiles, logistics, and pilot training. The package has been valued at over $1 billion, but China is reportedly covering 60–65 percent of its bill by bartering food, raw materials, and consumer goods. While the Russian military is skeptical about such sales, Russia's aviation industry is desperate for work. See *Aviation Week & Space Technology*, 5 October 1992, 28, and 17 July 1995, 40; *Far Eastern Economic Review*, 8 July 1993, 24, and Allen et al. 1995, 145–47.

47 The Su-27 is so advanced that the Chinese have reportedly had great difficulty providing proper maintenance and logistics for the first batch. The aircraft must be returned to the factory at Komsomolsk for any major overhaul. See Allen et al. 1995, xvii, 157–58, 174.

48 The MiG-31, with its look-down shoot-down Flashdance radar system, might be used in an airborne warning role to support an Su-27 strike. The Chinese reportedly sought 1,500 Russian engineers and technicians to help modernize an old F-7 factory in Guizhou to produce the MiG-31. If an agreement is reached, the Russians might be repaid, in part, with Chinese-made MiG-31s. See *Aviation Week & Space Technology*, 5 October 1992, and Allen et al. 1995, 158–59.

particularly if they can obtain production rights.[49] The F-10's first test flight may take place within 2 years, and initial operational capability might be achieved by 2005. Licensed production of the Su-27, however, could absorb the resources needed to bring the F-10 into production. Another aircraft program just entering production is the K-8 jet trainer jointly developed since the early 1980s with Pakistan, reportedly using U.S. technology.[50]

China thus has the capability to develop and produce fighters and their subsystems, but it needs foreign assistance and imported technology to achieve modern—let alone world-class—capabilities. China's economic opening in 1978 gave it access to European and, to some extent, U.S. technology and assistance. Its rapprochement with the Soviets in the late 1980s gave it access to Russian technology. However, a desire for self-reliance, tight defense budgets, and lingering foreign export controls have led China to emphasize reverse engineering, assisted development, and licensed production rather than hardware imports.

2. Commercial Co-production

China has made substantial progress improving the manufacturing capabilities of its aviation industry by producing parts for Western manufacturers. Production relationships with Western manufacturers have been part of a deliberate strategy implemented by the organization that controls aviation trade, China National Aero-Technology Import and Export Corporation (CATIC), to put China near the top of the "pyramid" of aviation suppliers.[51] China has sought support, assistance, and technology transfers in order to raise its civil aviation industry to meet international standards.

Rapid growth of China's airline industry created a large market for imported Western commercial transports. This development gave China leverage to demand co-production offsets when it purchased foreign aircraft. That is, in order to sell aircraft to

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49 The Russians reportedly offered in 1993 to co-develop the F-10, providing 60 to 70 percent of the technical design work and transferring production facilities to China. The F-10 is discussed in *Far Eastern Economic Review*, 8 July 1993, 24; *Aviation Week & Space Technology*, 13 March 1995, 26–27, and 27 March 1995, 44; Allen et al. 1995, 165, 186.

50 Pakistan is producing components for the K-8 and will assemble some K-8s at its Kamra factory. The K-8 reportedly uses a Garrett TFE731-2A turbofan engine and a license-produced Rockwell-Collins electronic flight instrumentation system. See Allen et al. 1995, 153, and Bitzinger 1991, 24.

51 See U.S. Congress, Joint Economic Committee 1993, 475, and *Aviation Week and Space Technology* 16 October 1995, 22.

China, foreign producers must agree to purchase aircraft parts made in China. Necessarily, that means foreign producers must help Chinese factories upgrade their capabilities so that the parts will be of acceptable quality.

Boeing, which dominates the Chinese market with over 200 aircraft sales, has purchased parts from Xian Aircraft Company since 1980.[52] By 2000, these purchases for 737 and 757 airliners should total some $600 million. Included are vertical and horizontal tail assemblies for the 737 among other components.[53] Further, Boeing will utilize some 20 Chinese engineers in designing parts of the new 737-700.

McDonnell Douglas' co-production program has been even more aggressive.[54] The company began purchasing Chinese landing gear doors in 1979. In 1985 it initiated a major program with Shanghai Aviation Industrial Corporation (SAIC) to assemble some 35 MD-80s, completing the last one in August 1994. The Chinese made the parts for 15 to 30 percent of the airframes they assembled. McDonnell Douglas had hoped to use this program to counter Boeing's market lead. Sales, however, were disappointing because China's airline industry became more decentralized, SAIC established a relatively high price for the MD-80s, and McDonnell Douglas was not permitted to import MD-80s made at its plant in Long Beach, California. Counting models made outside China, McDonnell Douglas has some 40 aircraft operating in China.

In 1992, McDonnell Douglas initiated its follow-on "Trunkliner" assembly program after winning a tough competition with Boeing.[55] The $1.6 billion Trunkliner effort will include 20 MD-90s built in Long Beach, California, and sold to China Eastern Airline and China Northern Airline. SAIC will assemble an additional 20 MD-90s at its Dachang plant. Chinese factories will produce 65 to 80 percent of the parts assembled at

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52 Boeing's co-production efforts are described in *Aviation Week and Space Technology*, 15 August 1994, 28–29, and 30 May 1994, 67.

53 Boeing reportedly has ordered 100 complete 737 tail sections from Xian Aircraft Company. The President of Boeing's Commercial Airplane Group has described the tail, now made in Wichita, as among the most difficult sections to make. As part of a $100 million investment in several China projects, Boeing is upgrading the state-owned Xian factory. By 1997–98, Xian will be able to make the tail and "build anything to world standards." See *New York Times*, 9 August 1994, and *Business Week*, 22 August 1994, 50.

54 McDonnell Douglas' co-production is discussed in *Aviation Week & Space Technology*, 21 February 1994, 62–67.

55 The Trunkliner program is discussed in *Business Week*, 16 November 1990, 52–53; *New York Times*, 14 June 1995, D4; and *Aviation Week & Space Technology*, 21 February 1994, 67, and 4 September 1995, 27.

Dachang, so China will be making much larger sections than it did under the earlier MD-80 program. For example, Xian Aircraft will make wings and fuselage sections, Chengdu Aircraft will build nose sections and passenger doors, Shenyang Aircraft will provide electrical wiring and components as well as the empennage, and SAIC itself will make leading and trailing edges for the wings. The principal imported components will be the engines and avionics. In addition, Chinese factories will make parts for use by McDonnell Douglas in its own factories, in order to help offset its purchases from McDonnell Douglas.[56]

The McDonnell Douglas programs have had a major impact on improving Chinese manufacturing capabilities.[57] Some 130 Long Beach personnel have helped train workers at Chinese factories in engineering, tooling, electrical, and especially management skills. McDonnell Douglas has contributed its expertise in design, production, and quality and airworthiness standards.[58] These efforts have had a broad impact for three reasons: Chinese aircraft companies are all owned by the holding company Aviation Industries of China (AVIC), Chinese practice is to transfer officials such as plant managers among companies frequently, and the program uses parts made by a number of companies. One indicator of Chinese quality is that McDonnell Douglas' Federal Aviation Administration (FAA) certification extends to the aircraft assembled by SAIC and five of those MD-80s have been sold outside China, to TWA. Chinese productivity in terms of assembly man-hours per aircraft is not as good as that achieved at Long Beach, but that is partially due to a lower rate of production at SAIC.

Airbus has a small but growing presence in the Chinese market, with 17 aircraft operating in China.[59] It has established co-production relationships with AVIC factories in Shenyang, Guizhou, Shanghai, and Xiaming. The major aircraft engine manufacturers,

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56 The new agreement will permit McDonnell Douglas to sell additional MD-80s or MD-90s made in Long Beach, a change that should limit SAIC's ability to overprice its aircraft as it did under the previous program. See *Aviation Week & Space Technology*, 13 March 1995, 63.

57 One reported characterization is that McDonnell Douglas jump-started China's commercial transport industry. See *Aviation Week & Space Technology*, 21 February 1994, 62–67; 4 September 1995, 27; and 2 October 1995, 56.

58 McDonnell Douglas has made other contributions to developing China's aviation infrastructure, for example, providing a model and test data to help develop wind tunnel test methods at the Aerodynamic Research and Development Center in Mianyang City, Sichuan. See Xikang 1989, 1, 7.

59 See *Aviation Week & Space Technology*, 16 October 1995, 22–23, and U.S. Congress, Joint Economic Committee 1993, 475–481.

including Pratt & Whitney, General Electric, Allison, Textron Lycoming, and Garrett, also have co-production or offset arrangements. For example, Pratt and Whitney and China National Lightweight Gas Turbine Development Center have jointly designed and manufactured the FT-8 gas turbine engine, which may soon be exported. Generally, in light of China's goal of industrial independence, foreign participation in the aircraft industry has not extended to include ownership. However, Allied Signal was recently allowed to own 51 percent of a joint venture with the Chinese Research Institute of Aero Accessories (CRIAA) to supply environmental control systems. It reportedly will supply engine parts for the K-8 fighter trainer and the Y-8 cargo plane. Parts eventually will be exported.

3. Chinese Commercial Aircraft

Over the years, China has produced a number of transports, such as the Y-7 and Y-8, for military or civilian use. In recent years, as Western co-production arrangements have helped raise manufacturing capabilities, the quality of China's commercial transports has improved.[60] Now, China is making a serious effort to enter the commercial export market on a significant scale.

China realized that it needed to upgrade its industry to international standards when it found it could not sell its Y-10 airliner, a downsized version of Boeing's 707. In 1984 it began development of the Y-12, a 17-passenger, twin-turboprop airliner. The Y-12, made by Harbin Aircraft Manufacturing Corporation, was granted a British airworthiness certificate in June 1990. Four planes have been sold to Laos and six to Sri Lanka. The aircraft's current version, the Y-12-4, was finally certified by the FAA in March 1995.[61] This certification represents a major milestone for the Chinese industry, demonstrating the improvement in its manufacturing standards. According to one McDonnell Douglas official, until recently certification would not have been possible.

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60 China has also imported sophisticated production equipment. In 1991, for example, four German digitally controlled multi-axis milling machines were observed at Shenyang Aircraft Company. in 1985 Shenyang, with IBM's help, set up a computer center that makes use of computer-assisted design (CAD) equipment. See Foreign Technology Division 1991, 8.

61 The Y-12 received so-called shadow certification under FAR Part 23. This means that the FAA did not itself supervise the Y-12's development and manufacture but instead reviewed and accepted the oversight reports of China's regulatory authority, the Civil Aviation Administration of China (CAAC). See *Aviation Week & Space Technology*, 2 October 1995, 56–60, and U.S. Congress, Joint Economic Committee 1993, 476.

Next, China will seek FAA certification of Xian Aircraft Company's Y-7 twin-turboprop airliner, the 50-passenger mainstay of China's regional airlines.

China's greater ambition now is to lead the development and manufacture of a 70- or 100-seat regional airliner, which China is calling the Asia Express or the AE-100.[62] This market segment is attractive to China—and to Japan, Korea, and Indonesia—because it is at the lower capacity edge of the market served by Boeing's 737 and the other major commercial producers. China's potential advantage is that its domestic market might absorb 250 out of the worldwide potential for 600 sales in this category over the next 15 to 20 years. An AE-100 blessed by China, and given preferential access to the Chinese market, would thus be a formidable competitor with a good chance of recovering its development costs. China appears to envision a cooperative project including Korea, which could offer financing and technical help. A Western aircraft manufacturer would participate to transfer the requisite technology and provide market distribution, but would be limited to a 20 percent share of the venture. China is now reviewing proposals from Boeing, McDonnell Douglas, Daimler-Benz/Fokker, and Alenia-Aerospatiale-BAC.[63]

China's commercial industry has thus made significant progress over the past decade or so. However, it has not reached the stage where it could indigenously develop and produce a global competitor such as the AE-100. It could nevertheless learn a great deal if it does succeed in leading such an effort.

4. Commercial-Military Integration

China's aviation industry appears to be substantially integrated, so that improvements in its commercial manufacturing capabilities can be readily transferred to its military products. The aircraft companies are all state-owned and, as noted above, are now part of the holding company AVIC.[64] Further, the individual companies produce both military and commercial products.

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62 See *Aviation Week & Space Technology*, 13 March 1995, 63 and 16 October 1995, 23.

63 Technology transfer is a key part of the competition since China hopes to use the AE-100 to raise its industry to international standards across the board, including engine manufacture. China is said to be a decade behind the West in commercial aircraft design, material science, and avionics. See *Business Week*, 25 December 1995, 50–51.

64 AVIC evidently has a charter to consolidate excess industry capacity and achieve overall profitability over a period of 3 years. See U.S. General Accounting Office 1994, 10.

Before the 1980s, China's aircraft manufacturers were dedicated mainly to production for defense aviation. However, as defense procurement budgets were cut and the military was downsized, the industry was left with substantial excess capacity.[65] Aviation and other defense industries were instructed to utilize their excess capacity to produce civilian products and contribute to the general uplifting of the civilian economy.[66] As a result, by 1993, civilian products unrelated to aviation accounted for some 70 percent of the aviation industry's output.[67] Industry products included such items as motorcycles and household appliances.

The commercialization of defense enterprises was part of a long-term program to modernize the Chinese economy and develop a technologically strong industrial base to support future defense production.[68] Short-term defense modernization was sacrificed as civilian needs were given priority. The expansion of defense enterprises into commercial markets was to some extent a holding action to maintain the viability of these organizations during the period of restrained defense spending. However, it also strengthened them through the experience of serving more competitive civilian and export markets, and in some cases gave them better access to foreign dual-use technologies.[69]

Military and commercial aviation production also became more integrated during this period as military factories increasingly served commercial aviation markets. Following are some examples for China's principal military aircraft manufacturers:

- The Harbin Aircraft Company manufactures bombers, including 425 B-5s from 1967 until 1988.[70] Harbin began production of the Y-12 commercial

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65 Fighter production peaked at 450 per year in the late 1970s but by 1985 had fallen to about 100 per year (Allen et al. 1995, 162). The defense operational budget fell quickly from a 1979 peak related to a border incursion against Vietnam, and then dropped more gradually (adjusted for inflation) from 1983 through 1988. The defense procurement account declined proportionately more than the operations budget. See Folta 1992, 18–20.

66 Defense industries had been given priority access to funding, supplies, technology, and skilled workers. It was thus believed that they could make a qualitative as well as quantitative contribution to the modernization of the national economy. They were actively encouraged to provide technical assistance to civilian enterprises. See Folta 1992, 4.

67 See U.S. General Accounting Office 1994, 10.

68 See Folta 1992, 16, 23, 32.

69 Ibid., 153, for a case study of enterprises making integrated circuits. Military and civilian production was integrated, sometimes on the same line. The two companies examined in detail utilized foreign production equipment and formed joint ventures with foreign firms.

70 See Allen et al. 1995, 228.

airliner in 1984 and achieved shadow certification by the FAA for a later version it now exports.

- The Chengdu Aircraft Corporation has produced the F-7 fighter since 1967. It was active in the abortive development of the Super 7 upgrade and is currently rumored to be the developer of the new F-10, using an Israeli military technical assistance team based at Chengdu.[71] Chengdu also produces nose sections for the McDonnell Douglas MD-80 and will build nose sections and passenger doors for the MD-90.
- Xian Aircraft Company has produced B-6 bombers since 1969.[72] In 1985 it began producing a modified B-6D for naval use and it is currently developing the FB-7 fighter bomber, also for naval use. At the same time, Xian produces the Y-7 commercial airliner mentioned above. Further, Xian has produced parts for Boeing since 1980 and, as noted above, Boeing is upgrading Xian's factory to produce complete tail sections for the 737. Xian will also build wings and fuselage sections under the McDonnell Douglas Trunkliner program.
- Shenyang Aircraft Company began producing F-5s in 1956, then made 3,000 F-6s through the early 1980s. It developed the F-8 and now produces about 2 per month.[73] Shenyang would also be the site for licensed production of the Su-27. Shenyang's commercial work includes cargo bay doors for Boeing's 757 and emergency exit doors and ribs for the Airbus A320. It will provide electrical wiring and components as well as the empennage for McDonnell Douglas' Trunkliner program. It also makes cargo doors for deHaviland's Dash 8 transport.[74] Other Shenyang products now include buses, medical and food processing equipment, and jeep-like vehicles.
- Guizhou Aviation Industrial Group previously produced F-7s and now produces F-7 parts and FT-7 trainers.[75] It reportedly was considered as a site

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[71] See *Aviation Week & Space Technology*, 27 March 1995, 44, for speculation on Chengdu and Xian as possible F-10 producers.

[72] See Allen et al. 1995, 152–54, 227–29. Incidentally, the Soviets have adapted the B-6 for their own use in both tanker and airborne early warning roles.

[73] See Foreign Technology Division 1991 and Allen et al. 1995, 164, 222, 233.

[74] The deHaviland program began in 1988. After start-up and training, Shenyang seems to be producing acceptable quality on time. The program is not part of an offset requirement and deHaviland reportedly will not hesitate to place future work with Shenyang (*Aviation Week & Space Technology*, February 21, 1994, 69). In another example of non-offset work, the appreciation of the yen has reportedly induced MHI to shift some of its work for Boeing's 777 to Shenyang Aircraft (*Aviation Week & Space Technology*, 1 May 1995, 36).

[75] See Allen et al. 1995, 154.

to produce MiG-31s with Russian assistance. Guizhou also produces maintenance equipment for the Airbus A320, A330, and A340.

It is important to note that these are large companies with multiple factories. It is not clear to what extent military and commercial products are produced within the same factory or on the same production line. It is nevertheless apparent that manufacturing improvements for commercial products can and do transfer to military products. A recent report by the General Accounting Office, for example, found that—

> In the People's Republic of China, sophisticated manufacturing technologies acquired through cooperative programs with the West are being adapted for Chinese military use. For example, flush-mounted riveting, once observed in China only on aircraft jointly manufactured with the West, is now seen on Chinese fighter planes that previously lacked this degree of sophistication. [76]

5. Dual-Use Observations

China's extensive military aviation industry provided a foundation for commercial aviation production at a fairly primitive level. However, China was able to upgrade its commercial manufacturing standards by trading access to its airliner market for technical assistance, training, and supervision by Western manufacturers. Because commercial and military production are integrated, at least at the company level, military manufacturing capabilities have also been improved. If China succeeds at launching a 100-seat regional airliner program, its development capabilities may also show a substantial improvement.[77] Still, China appears to have severe limitations in the development and manufacture of key avionics and weapons subsystems. China's potential is clearly limited, relative to Japan's, by the lack of strong supporting commercial industries for sophisticated electronics and advanced materials.

As in the case of Japan, China's belated development of commercial aviation exemplifies an attempt to strengthen the industrial base through dual-use production. This approach has already shown promise. China's experience producing military aircraft provided rudimentary capabilities for producing parts for foreign commercial airliner manufacturers and may be taken as a case of purposeful spin-off. Work for

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76 See U.S. General Accounting Office 1994, 7.

77 However, as noted above in the discussion of the FS-X, the development commonalities between fighters and commercial transports lie more in the general skills and infrastructure required than in specific technological solutions.

foreign manufacturers, in turn, greatly enhanced the manufacturing capabilities of China's integrated aircraft companies, thereby enhancing the production quality of domestic military and commercial aircraft through direct spin-on. Despite its efforts, however, China lacks the ability to develop and manufacture state-of-the-art military or commercial aircraft. Importantly, China lacks the strong national industrial base needed to support aircraft development with advanced electronics, materials, and other technologies.

C. TANKS AND HEAVY TRACTORS: THE EXPERIENCE OF VICKERS-ARMSTRONGS, LTD, UNITED KINGDOM, 1947–1960.

During the Second World War, Vickers-Armstrongs, Ltd., a subsidiary of Vickers, Ltd., developed and manufactured the Spitfire and Wellington. Vickers shipyards at Barrow and Newcastle supplied the British fleet with 146 submarines, 22 destroyers, a new battleship, and 9 aircraft carriers. The Elswick plant manufactured thousands of tanks, including the Centurion 50-ton medium tank, and the Crayford Works alone produced 20,000 machine guns. In documenting the history of the firm, Harold Evans said:

> It is almost certainly no exaggeration to say that without Vickers-Armstrongs the Second World War could not have been won.[78]

At the end of the First World War, according to Evans' 1978 history of the firm, Vickers had been left to cope on its own with the disruption to business of demobilization. In 1946, the British government "declared a wish to disarm by stages" and recognized a need to maintain new technology armaments' production in the post-war era. Nonetheless, the impact was major. According to *The Economist*, "After its great activity during the war years, the Vickers group inevitably experienced a sharp fall in profit in 1946, but the figures for the last year show that the concern has projected itself with vigor into the peacetime tasks of reconstruction." [79]

1. Tanks and Heavy Tractors

One postwar reconstruction project, promoted by the U.K. government, provided for Vickers-Armstrongs' expertise in the manufacture of tanks and tracked vehicles to be

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78 Evans 1978, 21.

79 "Vickers Group Reserves," *The Economist* 154 (1 May 1948), 728.

applied in the development and fabrication of heavy-duty crawler-tractors. The project was motivated by a complex mix of factors, including concerns for maintaining the industrial base, maintaining exports to third world suppliers of basic commodities, and maintaining industrial competitiveness vis-a-vis other industrial nations. In many ways, these concerns were similar to those facing the United States at the end of the Cold War, half a century later. According to Evans, "Government enthusiasm for this scheme was strongly linked with its desire to have available a heavy tractor of British design and manufacture, partly because of the shortage of dollars to buy American tractors. Vickers accordingly found itself under heavy pressure to push ahead as quickly as possible with a tractor project, the inducement being a projected 'immediate' order rate of 500 tractors per annum for the [East Africa] groundnut scheme." [80]

The East Africa groundnut scheme involved the clearing of forests and the planting of peanuts in large plantations in the British colonies, under the management of the Overseas Food Corporation. Such a task would require crawler tractors, of a design heavier than any manufactured in Great Britain, for forest clearing and soil preparation. There were American vendors of such equipment, but giving them substantial orders would have had a negative impact on the British trade balance with the United States, and the orders could not have been filled until 1950 at the earliest.[81] The exploitation and conversion of Vickers' capabilities for developing and manufacturing tanks not only would meet the immediate need, but also would help to lower the British trade deficit, retain heavy industrial manufacturing capacity in Britain, and provide an industrial mobilization capacity in the event that it became necessary to resume the manufacture of tanks. Moreover, a heavy duty crawler tractor could compete in both civil and military engineering markets.

To ramp up production as rapidly as possible, Vickers decided to undertake initial production by modifying the U. S.-made Sherman Mark III tank, which was available in Britain in large numbers. As documented in *The Engineer* and in *Engineering*, specifications for the tractor, which was designated the "Shervick," were set in October 1947, with a prototype produced by January 1948. The prototype was so successful that, by May 1948, large-scale production had already commenced. The Shervick mounted one of the two General Motors type 671 engines that powered the Sherman Mark III on a new

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80 Evans 1978, 21–22.

81 "Land-clearance Equipment for East Africa," *Engineering* 165 (28 May 1948), 513–516.

frame, together with the tank's gear box, clutch, transmission, radiators, suspension units, and tracks. The tractor used rear wheel drive, so the transmission was turned 180 degrees from that of the tank. Development of an attachable tree feller, tree stump remover, root cutter, and a root rake were subcontracted to an agricultural implements firm. The Shervick was manufactured at Vickers-Armstrongs' Elswick Tank Works in Newcastle. Symbolic of its dual use potential, the Shervick's prototype debut, on 20 April 1948, was attended not only by the Minister of Food and "representatives of the various Ministries and Departments interested in the East Africa scheme," but also by the Engineer-in-Chief and Director-General of Mechanical Engineering of the War Office.[82]

In spite of early enthusiasm, the Shervick was not needed as an interim product. According to Evans," . . . not many 'Shervicks' had been produced when the groundnut scheme collapsed." [83] Accordingly, while abandoning the Shervick design, Vickers continued with plans to develop a dual use heavy duty crawler tractor, shifting its efforts from production of an interim model to development of a new design. As Evans explained, "Vickers needed a new peace-time engineering product and the tractor seemed to offer a vast potential . . . It provided what seemed a sensible use of resources no longer required for defence production."

Vickers received some relief from the economic pressures of demobilization with the emergence of the Cold War. In 1950, production of the Centurion tank by Vickers-Armstrongs and the Royal Ordnance Factory was steadily rising, and would continue to rise through the second half of 1951. Perhaps ominously for Vickers, however, *The Economist* reported, "Most of the extra production will come from the ROF plant which has been working well below capacity. It is designed and equipped solely for tank production, and it is claimed that its specially designed layout has reduced costs by half, compared with those of other producers."[84] Taken at face value, *The Economist* article suggests that co-production of tanks and heavy tractors might have important disadvantages to the manufacturer.

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82 "The 'Shervick' Industrial Tractor, No. I," *The Engineer* 185 (23 April 1948), 400–401. "The 'Shervick' Industrial Tractor, No. II," *The Engineer* 185 (30 April 1948), 430–431. "Land-clearance Equipment for East Africa," *Engineering* 165 (28 May 1948), 513–516.

83 Evans 1978, 22.

84 *The Economist*, 4 November 1950, 706.

At the end of the war, the major producers of tractors in the U.K. were the Ford Motor Company and Harry Ferguson, Ltd. The Fordson "Major" weighed a little over 2 tons and was available in a 30 hp diesel or a gasoline engine model. The Ferguson tractor weighed a little over one ton and was available in a gasoline engine model only. A third producer, Nuffield, was entering the market with a 40 hp, 2.3-ton tractor, available in a half-track configuration. Demand was expanding greatly, with production up from 10,000 in 1938 to 118,000 in 1948. During the same period, exports rose from 5,800 to 68,000.[85] Vickers saw a commercial opportunity for a heavy tractor largely dependent on export markets.

By 1950, Vickers was able to announce a prototype, 14-ton crawler tractor, equipped with a six-cylinder, 180 hp Rolls Royce diesel engine; it anticipated full production of 500 tractors per year by 1952.[86] *The Economist* noted, "Tractors of this class have so far been built only in the United States, and American exports of them are considerable. Annual production is about 15,000 per year. Since 1947, Britain has spent $5,250,000 on imports of these tractors." *The Economist* reported that Vickers had spent over a million pounds on developing the tractor, whose reliability was expected to be high because of its reliance on a tested Rolls Royce engine, first built for tanks. Vickers had persuaded Jack Olding and Company, the British importer and marketer of American heavy tractors, to give up its agency, " . . . presumably on the assumption that imports to this country will cease when the home-built tractor becomes available." The only dark cloud on the horizon identified by *The Economist* was the possibility that the export market would shrink as post-war reconstruction projects were accomplished.

The Korean War provided an unstable context for the development, production, and sale of the VR-180 tractor. Soon after prototype testing began, the British government undertook a program of rearmament which led to multiple shifts at the Centurion production plants and plans for the opening of two additional assembly lines.[87] Although production of the VR-180 was publicly announced in February 1952,[88] the first

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85 "Tractors for Farmers," *The Economist* 156 (19 February 1949), 339–341.

86 "New Heavy Diesel Tractor," *The Engineer* 190 (4 August 1950), 132. "Heavy Diesel Tractor," *The Engineer* 190 (22 September 1950), 303. "New Heavy Tractor," *The Economist* 159 (22 July 1950), 192.

87 "Orders for Equipment," *The Economist* 160 (3 February 1951), 281. "Defence and Industry," *The Economist* 162 (8 March 1952), 614.

88 "The Vickers 'VR-180' Tractor," *The Engineer* 193 (29 February 1952), 326.

production model apparently was delayed until the next year,[89] a delay that was presumably caused by the priority production of Centurions.

The new tractor might have served Vickers-Armstrongs well in 1953, as orders for the Centurion were scaled back or canceled.[90] However, the dual-use design was not effective in civil applications. According to Evans, "Complaints from customers poured in." Neither the engine nor the transmission performed well" . . . and it was quickly apparent that the tractor would have to be re-designed and improved almost *in toto*." Some 300 tractors were recalled and the purchasers reimbursed. Evans explained the debacle this way:

> [This experience was] a rude shock for designers who now saw that the transition from armament design to commercial design contained unsuspected pitfalls. In armament design you expected to arrive at a high-quality product by a process of trial and error, but you proceeded by stages, and competitive costs did not have to be the first consideration as you introduced modifications. Moreover, it was not fully appreciated that tractors, unlike tanks, were likely to find themselves in the hands of unskilled drivers, particularly in developing countries, and that care and maintenance would be much more rudimentary. The Vickers tractor was, to quote one view, 'too delicate and too expensive.' Re-design and improvement against this background inevitably took time, but considerable effort was put into the task and in 1957 a really competitive machine, the Vigor, could at last be put on the market.[91]

The Vigor was an 18-ton machine, powered by a 180 hp, six-cylinder, Rolls Royce engine that was apparently an improved version of that which powered the lighter VR 180. Joining the Vigor was the Vikon, a 13-ton design, powered by a 143 hp, four-cylinder Rolls Royce diesel engine.[92]

Vickers' commitment to the tractor venture was demonstrated by its purchase, in 1954, of Jack Olding and Company, and the organization, in 1955, of Vickers-Armstrongs (Tractor) from Vickers-Armstrongs (Engineers), as the fourth operating company within the subsidiary firm.[93] The continuing dual-use nature of the project was

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[89] Evans 1978, 41.

[90] "Industry and Defence," *The Economist* 165 (13 December 1952), 769. "Dollars for Centurions," *The Economist* 165 (20 December 1952), 844.

[91] Evans 1978, 41.

[92] *The Engineer,* 14 November 1958, 771.

[93] Evans 1978, 40; *The Economist*, 21 April 1956, 306.

demonstrated by the fact that 60 of the first Vigors were purchased by the Royal Engineers.[94] Commenting on the purchase and the dual use applications for the Vigor, *Engineering* provided the following explanation:

> There is, in fact, a closer connection than is at first sight obvious. When the original Vickers tractor, of which this is a development, was designed, it was based on the fact that the rate at which a heavy tractor can perform is limited by what the operator can stand rather than what the machine itself will take. The tractor's suspension was therefore designed to travel over the most difficult terrain without losing speed, straining the hull, or causing undue discomfort to the operator. The springless, self-articulating suspension which resulted has something in common with that of a military tank, which also has to have fast travel rates combined with reasonable conditions for the crew.[95]

In spite of the military purchase, however, Vickers could not make a go of its reorganized tractor business. In the 1959 annual meeting, Viscount Knollys, the long-term CEO of Vickers, reported that a contraction in global construction equipment sales, combined with a saturated market, had prevented the firm from the sales needed to recover its production costs.[96] This critical problem occurred at a time of generally decreasing sales and profits for the firm, based on declining sales of aircraft and ships, and increasing development costs in a variety of high technology sectors. Sales declined from £89 million for the six months ending June 1958 to £73 million for the corresponding period of 1959, while profits decreased from £2.9 million to £1.8 million. A year later, business was looking up for the firm as a whole, but as Viscount Knollys reported, "It is satisfactory to be able to say that all our main engineering works, with the exception of Canadian Vickers and Tractors, are well filled with work."[97] The passing of Vickers-Armstrongs (Tractors) at the end of 1960 was not noted by Knollys in his 1961 report.[98]

Although the decision to close out the tractor venture was a minor part of Vickers' business and business history, it was a critical one for Vickers in its transition from a defense firm to a general business corporation. "Moreover, it involved a change in the collective attitude of mind of the Vickers group," Evans explained. "The Group had been

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94 *The Engineer,* 27 February 1959, 337.

95 *Engineering*, 6 March 1959, 319.

96 *The Economist,* 6 June 1959, 971.

97 *The Economist*, 11 June 1960, 1137.

98 *The Economist*, 10 June 1961, 170.

accustomed to rely on Government orders for armaments, and the attitude to commercial products had been that Vickers never gives up."[99] Speaking to a strategic planning conference of the directors of the firm, Knollys explained, "This traditional attitude has resulted in avoidable losses, . . . and unprofitable activities should now be looked at objectively and discontinued where no prospect of a reasonable return can be seen."[100]

Evans sums up Vickers' tractor venture this way:

> Now, at long last, after 13 years, a decision had been taken to wind up the tractor company. For the engineers, with their professional pride deeply involved, this was a bitter blow. In the late 1940s the call to design and build a British industrial tractor capable of holding its own against American competition, must have made every kind of sense. Vickers had a long experience in building tracked vehicles for the Army. To adapt this experience to a heavy tractor was a challenge they could accept with total confidence. Moreover, the world market for heavy tractors in the period of post-war reconstruction looked almost insatiable. For Vickers this was surely the splendid new commercial product—a product of their own design and manufacture—they needed to replace armament work . . . .
>
> In all, the loss since commercial production began was estimated at £9.4m. More important, perhaps, was the loss of time and effort which might have been used more fruitfully in other projects. In 1960, the Engineers were still without a major commercial 'own product', and still mainly dependent on manufacturing and sales licenses for commercial products and on armaments. For growth it was necessary to look to acquisitions.[101]

The immediate reasons for Vickers' failure in the tractor business, which Evans identified nearly 20 years ago, included many of the concerns found in the contemporary literature on dual use and defense conversion issues:

- Vickers' design engineers participated in a different design culture and followed different design traditions from those appropriate to the commercial sector.
- Vickers failed to appreciate the implications for design of differences in training and infrastructure in the civil sector.
- The marketing firm Vickers hired, then acquired, though experienced with the product, had no experience in the principal markets where the product

[99] Evans 1978, 39–40.

[100] *The Economist*, 6 June 1959, 971.

[101] Evans 1978, 40, 42.

must be sold if income were to be sufficient to provide an adequate return on investment.

- During the period that Vickers learned to design, produce and market the commercial product, the market for that product changed. There was a worldwide overproduction, and wheeled tractors had begun to replace crawler tractors in many heavy applications.

To these observations may be added several others: During the 13 years 1947–1960, global trading patterns changed drastically. Imperial markets, which Britain had been able to take for granted, became competitive. Britain's role as the world's leading industrial nation and a leading exporter of heavy machinery had been undermined by the costs of empire and of global warfare. The United States, largely free of the burden of empire, had been poised to supplant Britain in heavy machinery exports before the war. In the specific case of heavy tractors, Vickers was faced with competing against the United States in a market where, because of domestic markets American firms were already dominant. Another complicating factor, not identified by Evans but implicit in the apparent delay in production of the VR-180 during the Korean War, may have been an underlying priority within Vickers to the defense sector whenever civil sector opportunities came in conflict. Finally, as reported in *The Economist* regarding the production costs of the Centurion tank at the Royal Ordnance Factory, it may be that the economies of production sometimes favor a single product. None of these factors are definitive or universal, but they all warrant consideration in the planning of dual use strategies.

Vickers' conception of a demonstrably useful product, its technical capability to develop the product, its manufacturing experience in building similar defense products, and its acquisition of a firm with the capability to market the product nonetheless failed to ensure a successful dual use or defense conversion program. Over the 13 years Vickers took to learn to bring a viable design to market, the market had changed in ways that benefited those American firms that enjoyed the advantage of an initial market share. Vickers' attempt to employ its design expertise and production base for military tanks to the development and sale of dual use heavy duty tractors was an expensive failure.

2. Dual-Use Observations

Vickers' attempt to build crawler tractors illustrates a failed effort to apply military tank technology to a commercial product through purposeful spin-off. The British government, adopting a strategy consistent with our industrial base strengthening model, supported the project in order to achieve broad national goals, including the preservation of heavy industry and a reduction in the overall trade deficit. Vickers itself viewed tractor-building as way to offset declining military orders. Tanks and crawler tractors seemingly had important commonalities, including heavy workloads and tracked operation over rough terrain. Over a period of 12 years, Vickers engineered a series of crawler tractors utilizing tank engines, transmissions, and other components. Eventually, Vickers withdrew from the tractor market, having failed to develop and sell commercially suitable products. The Vickers story illustrates the great difficulty that a strongly defense-oriented firm can have understanding and penetrating commercial markets, using products and engineering skills optimized for military purposes.

D. MILITARY AND CIVIL TRANSPORT AIRCRAFT: EMBRAER AND THE BANDEIRANTE TURBOPROP, BRAZIL, 1970–1990

In 1969, the Brazilian government organized a new firm for the development and production of aircraft, Empresa Brasiliera de Aeronautica, S.A., commonly known as Embraer, with the government the major stockholder. Incubated within the Departmento de Aeronaves of the Brazilian national government, starting in 1966, Embraer began corporate operations early in 1970.[102] The firm began its existence with five major projects:

- Development and production of the Ipanema agricultural aircraft (crop duster).
- Development and production of the Urepema sailplane (a dual-use design).
- Licensed production of the Aeronautica Macchi MB326GB jet trainer.
- Development of a short take off and landing (STOL) turboprop-powered military transport and assault aircraft.
- Development and production of the Bandeirante (pioneer, in English), a Brazilian-designed, twin-turboprop transport (dual-use).[103]

1. The Bandeirante

The first order for the Bandeirante was for 80 aircraft for the Brazilian Air Force to replace its fleet of Beechcraft C-45s. Embraer's commitment to a dual-use design was evident in its application to the U.S. Federal Aviation Administration for certification

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[102] Taylor 1970, 11.

[103] Brown 1971, 62.

under U.S. Federal Air Regulation, Part 23, and in its early conduct of a global survey of commercial markets.[104]

Two prototypes had been built prior to the organization of Embraer, and two more were under construction. Perhaps as a result of the survey, the design underwent substantial change, from a 10- to an 18-passenger aircraft, before the first production model was delivered for certification testing in August 1972, and the first three were delivered to the Brazilian Air Force in 1973.[105] By October 1973, Embraer had orders for an additional 19 planes in a commercial passenger configuration from domestic Brazilian carriers.[106]

The Bandeirante was a very successful product. The first two Bandeirantes were delivered to U.S. customers in 1978. By 1984, over 400 Bandeirantes had been sold, more than half for export, including, as of 1982, 97 to commuter airlines in the United States, representing a U. S. market share of 33 percent, for 15- to 19-passenger turboprop aircraft.[107] Production of the airplane, which peaked in 1980 at 73 aircraft,[108] was terminated in 1990, with the 500th Bandeirante, which, like the first, was sold to the Brazilian Air Force.

Of the 500 airplanes, 156 were delivered to the Brazilian Air Force, including 2 EC-95Bs for navaid calibration, 5 search and rescue SC 95Bs, six reconnaissance aircraft (R-95B), 22 maritime surveillance craft (P-95 and P-95B), one XC-95B for artificial rain research, and 108 C-95 transports (base, A and B models), together with 12 C-95Cs, equipped with electronic flight instrumentation systems.[109] Military versions were also

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104 Ibid., 62, 65; *Janes* 1970, 11.

105 *Jane's* 1984, 10.

106 Brownlow 1973, 42.

107 Sarathy 1985, 64.

108 *Aviation Week,* 9 November 1987, 78.

109 Lambert 1990, 11.

delivered to the nations of Chile and Uruguay,[110] Gabon and Angola.[111] Thus, about 40 percent of the Bandeirante were produced for military customers, and about 60 percent for commuter airlines.

Embraer has built upon its success with the Bandeirante, designated the EMB-110 (except for the maritime surveillance version, the EMB-111), with the design, development and manufacture of the EMB 120, Brasilia, a 30-passenger turboprop, introduced in 1985. The first customer to take delivery of the Brasilia was a U.S. carrier, Atlantic Southeast Airlines. Owing largely to the success and reputation of the Bandeirante, orders for the Brasilia, as of March 1990, stood at 291, including 9 delivered to the Brazilian Air Force.[112] Embraer forecast a total production of 400 aircraft,[113] and in 1989, launched development of a 45-passenger, stretched, turbofan version of the Brasilia, designated EMB-145. Not all of Embraer's projects have been successes, however. The short takeoff and landing aircraft which was one of the five original Embraer projects apparently never got off the ground.[114] Embraer initially planned delivery in 1991 of a much publicized, twin-pusher turboprop of radical design,[115] but as of 1995, the plane was not yet in production.

The leading motive for the establishment of Embraer and for the development of the Bandeirante was the national interest of the nation of Brazil as perceived by the government including the military. According to Cecil Barlow, correspondent for *Aviation Week and Space Technology,* writing in 1975, the major impetus to the Embraer venture was the perceived need by the Brazilian government " . . . to drive down the volume of aerospace imports in a country relying strongly on aerospace hardware and techniques." In 1973, nearly 5 percent of all Brazilian imports went to the U.S. aerospace industry, and there were no Brazilian exports of aerospace equipment. The production of military aircraft to avoid imports was an important goal. *Jane's* 1970 report on the new venture mentioned only military models for the Bandeirante, then in prototype, including a transport model, a navigation trainer and an aeromedical evacuation aircraft (p. 11).

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[110] *Aircraft Engineering* 1980, 4.

[111] Lambert 1990, 11.

[112] Ibid., 1990, 12.

[113] *Aviation Week*, 9 November 1987, 78.

[114] Brown 1971, 62–64.

[115] *Aviation Week & Space Technology*, 1986, 128; and 1987, 78.

Nonetheless, Embraer was established to be a competitive firm in the international marketplace from the beginning. Although the government held 51 percent of voting stock, and thus retained government control of the aircraft manufacturer, about 80 percent of capital came from private sources that expected a return on their investment. According to a 1980 analysis by the British journal *Aircraft Engineering,* "The Federal Government [of Brazil] owns 12.4 percent of EMBRAER stock, and the remaining shares are held by more than 175,000 Brazilian companies. It is intended to be and, in fact, is a profit-making company. Both because of governmental participation and the broadly based ownership by the Brazilian public, EMBRAER is often referred to as 'the Brazilian national aeronautical manufacturer.'" (p. 2).

Embraer's success at developing and marketing a dual-use aircraft was not a foregone conclusion, when the venture was launched in 1970. The risk associated with establishing a viable, intermediate-to-high technology aircraft industry in a developing nation is intuitively high, and observedly exceptional. One important issue related to the dual-use concept was identified by *Aircraft Engineering* in 1980:

> There is often a tendency for the aeronautical industries of nations with limited civil markets to become excessively dependent on government orders for military aircraft. The examples in which this is true outnumber those where it is not. Even in the United States, the proportion of aircraft production going to military applications is high. In the case of Brazil, a reasonable balance between civil and military production has existed since the creation of EMBRAER. The military production has been only what the country generally needs, and only that for which the domestic industry is competitive . . . The maintenance of such a civil-military diversification is another source of resiliency of the industry in case of unforeseen changes in the demand for any specific type of product (p. 4).

The major success of the Bandeirante was partly the result of success in the U.S. commuter market. With the Bandeirante as its principal initial product, Embraer entered a market that was dominated by U.S. manufacturers. The Beech B99, introduced in 1968, was a 15-passenger, unpressurized turboprop aircraft with a range of 630 miles. The Fairchild Metro, introduced in 1970, had a pressurized cabin and could carry 19 passengers up to 1,000 miles.[116] When the Bandeirante was brought to the U.S. market in 1979, these two aircraft, together with the older Canadian DeHavilland Twin Otter

[116] Sarathy 1985, 61.

split the U.S. market about evenly with about 100 aircraft each.[117] Competition could also be expected from the Australian GAF Nomad, and the German Dornier DO-200 series. Sarathy noted, however, that as of 1982 "Dornier has had no [American] orders for its planes, while Australian GAF has withdrawn the Nomad from the market for lack of customer response" (p. 64). Characterizing the American market of the early 1980s, Sarathy said, "Mid-sized commuter aircraft are approximately 28 percent of all aircraft used by commuter airlines and . . . only a third of the commuter airlines actually use such midsized planes. While mid-size commuter aircraft represent a definite niche in the commuter plane industry, it is not very large. Market growth would have to come from fleet expansion, from increase in the number of commuter airlines flying mid-sized planes, and from upgrading of fleets as passenger traffic grows and as larger planes are needed" (62–63). By 1982, Embraer had captured a 33 percent market share of an expanding North American commuter airline market. With the Bandeirante, Embraer achieved a high level of success in a difficult market where other worthy competitors failed.

Aviation industry reporters are consistent in their analysis of the Bandeirante's success. A major factor, of course, was good design. Upon seeing the export, passenger version of the EMB-110, aviation reporter David North wrote, "Embraer's two new passenger versions of its EMB-110 Bandeirante family of turboprops . . . are designed for rugged operations, comfort, flexibility and reliability and are making a sales impact in the international commuter market."[118] North specifically noted the aircraft's quick change cargo/passenger conversion capability—a design factor which reflected the military model's passenger—air evacuation conversion capability. He noted the oversized landing gear, and the overall construction for "rough field operations, as well as a reputation for unusual reliability, reported by Brazilian commercial operators. Moreover, after test-flying the plane at the Embraer plant, North reported, "The Bandeirante is a pilot's aircraft. The cockpit is uncluttered, with all the controls and system switches reached easily from the left seat. The aircraft also offers passengers spaciousness and a lavatory not found in most commuter aircraft" (p. 54). In 1980, *Flying* magazine reported, "It handles like a Piper Chieftain, but it can haul up to 21 seats at nearly 220 knots and collapse its [landing] gear for do-or-die stops." An American commuter airline's

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[117] Ibid., 63.

[118] North 1978, 51.

maintenance director reported that the Bandeirante, affectionately known as the Bandit, compared to the Chieftain in maintenance expense even though its larger capacity (over 10 seats) required a daily maintenance release (p. 36). As the author commented, "Some of the Bandeirante's American competitors no doubt read more than affection into the 'Bandit' nickname. They are irked that domestic commuter airlines would buy abroad when there is such a large industry to patronize at home" (p. 33). The British journal, *Aircraft Engineering,* evaluated the Bandeirante this way:

> The Bandeirante has proven to be such a good airplane that it is likely to go down in aviation history as a classic of its type. The virtues of the basic design, shared by all Bandeirante versions, have been praised by pilots, airworthiness licensing authorities, the world's aviation press and operators alike: a perfectly balanced combination of utility and performance, efficiency and economy, reliability and trouble-free operation, comfort and excellent handling qualities at a reasonable sales price [about $1.1 million at introduction in 1978 (North 1978b, 36)]. The success of EMBRAER is due in large measure to the success of this Brazilian product (p. 4).

Not only good design, but nichemanship played a role in the Bandeirante's success. New Haven Airways chose the Bandeirante to replace its Piper Chieftains as passenger loads rose. "The Bandeirante was the only aircraft that fit the speed, cost and size goals set by New Haven in its search for larger equipment."[119] Good manufacturer support also played an important role: Embraer established a full service and maintenance subsidiary, Aero Industries, Inc., in three U.S. locations,[120] as the first U.S. aircraft went into service. Other important factors, according to *Aircraft Engineering* (1980, 2–5), were detailed strategic planning of R&D, training of the workforce, and production capacity, access to test facilities and knowledge resident at the Aerospace Technical Centre (CTA), Brazil's equivalent of NASA, and a diversified product line.

Favorable financing offered by Brazilian banks and subsidized by the Brazilian government played a role in the Bandeirante's success, but as Sarathy points out, in explaining the Bandit's success at the expense of American manufacturers, "The problem of competing with subsidized export credits is not unique to the case of the Bandeirante," citing Airbus Industrie and British Aerospace, concluding, "All in all, such cheap credit represents a common problem in competing with state-owned enterprises." Sarathy

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[119] *Flying* 1980, 35.

[120] North 1978b, 36.

maintained that cheap credit was especially attractive to commuter airlines, whose financial position was typically shaky, but concludes "Embraer's success was not due solely to subsidized credit; careful product planning and attention to marketing also contributed to its success." American firms, in fact, declined to compete in the mid-sized commuter aircraft niche, because they saw more profit in a different niche for mid-sized aircraft, that of corporate turboprops.[121]

Although there are many differences between the military-industrial situations in Brazil and the United States, the two nations and their industrial firms operate in a common global technological and market context, and with common national goals. The desire to maintain a domestic manufacturing capability in certain critical military technologies was an important motive to the establishment of Embraer, a goal shared by the United States in a variety of technology areas. Brazil was also concerned with balance of payment problems associated with the import of technological products manufactured overseas when a domestic production capability was feasible. The U.S. faces analogous situations, notably in several electronics sectors. Moreover, Embraer faced a common problem for large-ticket, low production products, the need to aggregate markets in order to achieve sufficient production to provide a positive return on investment. In the United States as in Brazil, this need can be a major motive for dual-use development of technology systems.

The Bandeirante represents a successful case of dual-use technology development and innovation from which several lessons can be drawn. Perhaps most important is that the Bandeirante was a business success. Whatever its government affiliations, Embraer approached the Bandeirante project as a commercial venture requiring careful strategic planning in the development of a product, of a work force, of a marketing organization, of support services, and of follow-on products. Its commitment to the commercial product was deep, even to the point that military deliveries were delayed. According to Sarathy, "As civilian demand began to increase for the Bandeirante, the military proved quite accommodating, allowing every other plane on order to be diverted to the civilian market."[122] Such an accommodation would require new U.S. attitudes regarding military vs. civilian priorities in the post-Cold War era.

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[121] Sarathy 1985, 70–74.

[122] Ibid., 67.

A related point is that the Bandeirante relied on good design for a particular market niche to achieve initial market entry. Subsequently, Embraer has expanded its horizons to include larger, pressurized, and turbofan aircraft, building upon solid success in a niche market. Embraer made a virtue of military design features within that niche. A combination of ruggedness, high reliability, and low maintenance offset certain design disadvantages, such as relatively high fuel consumption and short range, in the decision-making process of civilian customers. Also, Embraer built upon a solid base of domestic military and commuter airline customers, reducing the overall market risks. The exploitation of export markets occurred only 5 to 7 years after initial production and domestic sales. Many of these experiences can provide lessons for planning of dual-use ventures today.

2. Dual-Use Observations

Embraer's Bandeirante provides yet another example of the successful pursuit of dual-use capabilities in furtherance of broad national objectives, a strategy that we have termed *industrial base strengthening*. The product greatly improved Brazil's aerospace trade balance and established a valuable and enduring national technological capability. The Bandeirante family of aircraft evidently satisfied Brazil's military requirements and demonstrably succeeded in commercial markets, both at home and abroad. Both military and commercial needs influenced the Bandeirante design, with the military requiring ruggedness and easy convertibility between passenger and other configurations through purposeful spin-off, and the commercial market influencing the choice of aircraft size. Embraer's success particularly reflects its firm commitment to both military and commercial markets from the beginning, and its resultant structuring to achieve that dual-use strategy.

E. IMPLICATIONS FOR DUAL-USE PROGRAMS

The foregoing five examples of dual-use in other countries support our assertion in Chapter 5 that a closer working relationship exists between government and industry abroad. In turn, this closeness provides greater flexibility for structuring and managing dual-use programs to benefit both commercial and military sectors. In extreme cases, such as China, where military and civil needs are met jointly using common state-owned facilities and processes, the issue of transferring information, technology, and capabilities between the two sectors—spin-off of military technology for commercial use and spin-on of commercial technology for military use—becomes moot. In less extreme cases, such as Japanese and Brazilian aerospace activities, the avenues for transferrence are nonetheless unencumbered and work to the advantage of both sectors, particularly industrial base strenghthening. Nevertheless, as the Vickers example clearly demonstrates, care must be exercised when developing dual-use strategies—elegant technological solutions cannot take the place of market demand or understanding the needs of one's customers.

Given the current political climate in the U.S., it is highly unlikely that government and industry will draw closer in their activities in the near future. Even so, the possibility of structuring some portion of a dual-use program so that it mimics foreign successes may be an attractive dual-use strategy in selected instances. In particular, this option could be applied when foreign government support will lead to the exit of U.S. firms from key technology areas, or where the advance of foreign capabilities through industrial policies poses a security threat. However, given the increasingly transnational operation of MNEs and the proliferation of cross-border inter-firm alliances, we must carefully scrutinize who will ultimately benefit from the expenditure of U.S. taxpayer dollars.

F. SUMMARY

- The foreign dual-use efforts disucssed in this chapter individually and collectively represent a blend of the four dual-use program models introduced in Chapter 2. Because the relationship between government and industry is much closer in other countries than it is in the United States, foreign governments tend to view their national interests from a more unified perspective, considering economic and military security one and the same. As a result, government technology and industry assistance programs combine both commercial and military goals whenever possible. The notion that there is a need to separate the interests of the public and private sectors is, at best, "foreign."
- Japan's FS-X development illustrates the integration of national research and manufacturing technology bases in pursuit of industrial base strengthening. Integrated aircraft manufacturing through licensed production of foreign military aircraft, together with government-sponsored indigenous development of fighters and an unsuccessful commercial airliner, enabled the Japanese to produce and eventually co-develop parts for foreign airliner manufacturers through purposeful spin-off. This subcontracting work also led to technology transfers and experience useful for the FS-X development through concerted efforts at direct spin-on. Other technologies needed for the

FS-X were developed based on years of targeted research funded by the Japan Defense Agency (JDA) as well as company- and government-funded research in Japan's advanced electronics, materials, and other supporting industries—indirect spin-on.

- The development of the co-cured composite wing for the FS-X exemplifies dual-use via industrial base strengtheing within a component of the Japanese aircraft industry. Aircraft manufacturers gained experience manufacturing composites through JDA-funded research and licensed production of military aircraft. That know-how qualified them to make composite parts for foreign airliner manufacturers (another case of purposeful spin-off), from whom they gained more advanced composites technology that proved useful through direct spin-on in developing the FS-X wing. In turn, Japan's FS-X experience enhances its capability to make composite structures for future commercial airliners, a purposeful spin-off of a direct spin-on. Over the years, government-supported research on composites has helped Japanese companies develop markets for composite sporting goods and other products, enabling aircraft manufacturers to draw on a strong infrastructure of composite materials and equipment suppliers. This scenario may be viewed as both industrial base strengthening and indirect spin-on.
- China's belated development of commercial aviation exemplifies an attempt to strengthen the industrial base through dual-use production. This effort has already shown signs of success. China's experience producing military aircraft provided rudimentary capabilities for producing parts for foreign commercial airliner manufacturers and may be taken as a case of purposeful spin-off. Work for foreign manufacturers, in turn, greatly enhanced the manufacturing capabilities of China's integrated aircraft companies, thereby enhancing the production quality of domestic military and commercial aircraft through direct spin-on.
- Vickers' attempt to build crawler tractors illustrates a failed effort to apply military tank technology to a commercial product through purposeful spin-off. The British government, using a strategy consistent with our industrial base strengthening model, supported the project in order to achieve broad national goals, including the preservation of heavy industry and a reduction in the overall trade deficit. Eventually, Vickers withdrew from the tractor market, having failed to develop and sell commercially suitable products. The Vickers story illustrates the great difficulty that a strongly defense-oriented firm can have understanding and penetrating commercial markets, using products and engineering skills optimized for military purposes.
- Embraer's Bandeirante provides an example of the successful pursuit of dual-use capabilities in furtherance of broad national objectives, a strategy that we

have termed *industrial base strengthening*. The Bandeirante family of aircraft evidently satisfied Brazil's military requirements and demonstrably succeeded in commercial markets, both at home and abroad. Both military and commercial needs influenced the Bandeirante design, with the military requiring ruggedness and easy convertibility between passenger and other configurations through purposeful spin-off, and the commercial market influencing the choice of aircraft size. Embraer's success particularly reflects its firm commitment to both military and commercial markets from the beginning, and its resultant structuring to achieve that dual-use strategy.

- These five examples of dual-use in other countries support our assertion in Chapter 5 that a closer working relationship exists between government and industry abroad. Nevertheless, care must be exercised when developing dual-use strategies—elegant technological solutions cannot take the place of market demand or understanding the needs of one's customers. Given the current political climate in the U.S., it is highly unlikely that government and industry will draw closer in their activities in the near future. Even so, the possibility of structuring some portion of a dual-use program so that it mimics foreign successes may be an attractive dual-use strategy in selected instances. However, given the increasingly transnational operation of MNEs and the proliferation of cross-border inter-firm alliances, we must carefully scrutinize who will ultimately benefit from the expenditure of U.S. taxpayer dollars.

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VII. BUILDING DUAL-USE PROGRAMS

The preceding chapters examined past approaches to dual-use in the United States. Prior to World War II, particularly during the interwar period, dual-use was generally undertaken in a collaborative government-industry environment that was amenable to all four programmatic models outlined in Chapter 2: purposeful spin-off, direct and indirect spin-on, and industrial base strengthening. During the Cold War, on the other hand, the U.S. Government generally eschewed industrial base involvement,[1] and dual-use was mostly limited to serendipitous spin-off and well-defined militarily-relevant spin-on activities. By contrast, historically, other countries have engaged in all aspects of dual-use, their more permissive political environments proving conducive to the close government-industry relationships necessary to successfully pursue such policies.

This chapter explores how the United States can direct resources to pursue a DoD-led dual-use program as a successor to the TRP. Because dual-use was not part of explicit DoD policy prior to the Clinton administration, we approach this subject from two different perspectives. First, we draw upon the literature reviewed for this paper to consider various authors' recommendations and positions on programmatics. Then, we take advantage of our own extensive experiences with the TRP to consider issues regarding the integration of commercial products and processes with the needs of the military, recommendations for selecting dual-use investment focus areas, legal and institutional matters, and issues surrounding the actual operation of a dual-use program.[2]

A. DUAL-USE AND INDUSTRIAL BASE INTEGRATION

Dual-use investment is but a small part of aggregate DoD program investment activities, as discussed in Chapter 2, and despite the increasingly dual-use nature of many technologies, defense-specific production activities are still the norm. DoD could,

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1 Note that SEMATECH is a prominent exception of government involvement in industrial base strenghening.

2 As mentioned in Chapter 3, DARPA has "informally" employed a dual-use approach when investing in many technologies to pursue military missions during its 37 year history.

however, seek to reduce the differences between the process technologies employed in the production of military and commercial systems to take advantage of commercial economies of scale and scope, as well as other efficiencies. Some products could be co-produced in the same facilities and, in some cases, on the same production lines. In that eventuality the performance of a greater number of commercial sectors of the economy would become "directly" defense relevant.

One cannot assume, however, that private industry will flock to co-produce military and commercial products. This will be true only where the rate of return on investment from co-production exceeds that of commercial production alone. Even now some companies reportedly refuse to bid on government contracts because the anticipated rate of return is not high enough to warrant their attention, and they find procurement practices and standards bothersome and inefficient.[3] Thus an important step in devising a formal dual-use program is to identify the rationales that would attract commercial firms to engage in dual-use pursuits.

The economics of dual-use demonstrates that government must make it worthwhile for commercial firms in the private sector to do business with DoD. But the government must take care not to upset the balance of the marketplace through its actions. Particularly in cases where strong scale or scope opportunities are likely, the government must avoid driving out competition by giving any one firm an edge over another. The purpose of dual-use is to take advantage of efficiencies spawned in a competitive marketplace, not to create inefficiencies through ham-handed policies and inadvertent monopolies.[4]

Even with the full cooperation of commercial firms, co-production opportunities may not be fully realized unless the government reforms the way it does business with the private sector—and not merely with regard to regulations. The government must learn and, where possible, adopt the culture of commercial industry so that government practices become consistent with those of transnational firms in the global marketplace.[5]

One long-time proponent of the military's increased reliance on the commercial industrial base through commercial-military integration (CMI), Jacques Gansler, argues that it is the military that must harmonize its approach to technology investments and

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3 U.S. Congress 1994, 74.

4 See, in particular, White and Tai June 1995, 23–40.

5 See the conclusions and recommendations in Bingaman et.al. 1991, 85–95.

acquisition with that of the commercial world. (Appendix A of the present paper lists 16 lessons learned from his experience in the Pentagon relevant to improved industrial base integration and reliance on dual-use.)[6] As he points out, there are rational economic decisions that profit-maximizing commercial firms will make regarding industrial base integration. Where advantages may arise through the increased use of excess production capacity, such as through co-production, or from an expanded scale of operations, subject to the elimination of costly nonmarket barriers, private sector investments will be made. The willingness of firms to compete for business in an integrated commercial-military industrial environment will then depend on the competition policies adopted by government decision makers, as well as other business and economic factors in the global economy.

In the same vien, the Center for Strategic and International Studies has published two reports[7] that recommend specific changes in the acquisition system to pursue industrial base integration (see Appendix A). Among the areas recommended for change are accounting and specifications requirements, technical data rights policies, and the operation of the federal laboratory system. More specifically, the CSIS Executive Committee on Defense Conversion cautioned that "DoD must stop thinking in terms of a defense industrial base (DIB) and start thinking in terms of an industrial base available for defense (IBD). The essence of the IBD concept is to leverage existing dual-use capabilities for defense while at the same time subsidizing those capabilities that do not exist or would otherwise disappear from the civilian sector."[8] This includes the need for DoD planners to seek-out dual-use solutions to their problems.

Also weighing in on industrial base integration, the Office of Technology Assessment issued four reports on the subject from 1991 to 1994. The key findings of these are quoted below (see Appendix A for a more complete text):

From *Assessing the Potential for Civil-Military Integration* (1994):

- Not all technologies, industrial sectors, or industrial tiers are equally amenable to integration. (p. 10)

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6 Gansler 1987, 138–158.

7 Bingaman et al. 1991 and Brown et al. 1994.

8 Brown et al. 1994, 2.

- The implied estimated savings of 20 to 60 percent for some individual case studies and savings of factors of 10 in a few selected cases, do not translate into proportional savings across the entire DTIB. (p. 11)
- OTA estimates place total potential cost savings from increasing CMI might be from a few percentage points to as high as 15 to 20 percent of baseline DTIB spending depending on the set of policies implemented; applying these estimates to Defense Science Board Task Force on Acquisition Reform to OTA's estimates, gives an overall estimated cost savings in the range of 5 to 10 percent of estimated baseline spending. (pp. 14–15)
- If CMI is successfully implemented, its most important contribution may not be savings, but instead the preservation of a capability to support future national security objectives. (p. 15)

From *Defense Conversion* (1993):

- ARPA is becoming, de facto, a dual-use technology agency with a wide range of responsibilities. However, it is still a defense agency with the primary mission of meeting military needs. Despite the overlaps in technologies having both defense and commercial applications, the match is by not means complete, nor are priorities necessarily the same. (p. 29)

From *Building Future Security* (1992):

- Advanced technology remains critical to the Nation's military strength. But the narrow focus on battlefield performance during the cold war should give way to a broader approach that takes account of defense manufacturing and maintenance issues and economic security. (p. 8)
- For much of the military materiel required by the DoD, OTA's analysis suggests that for reasons of cost, total capacity, and potential for innovation, the path defined by choosing dual-use technologies, private ownership, and competitive acquisition is preferable to alternate paths. (p. 9)
- An advanced defense R&D capability includes world-class personnel (individuals and teams); cutting-edge research that guards against technological surprise; robust efforts in critical technologies; a balance between the near-term technology needs of each Service and the long-term U.S. defense needs; strong links to manufacturing so that proposed weapons systems are producible; and integration with civilian R&D, even in the absence of a national consensus on directed federal support for civil technology programs. (p. 11)
- The DoD must make great efforts to exploit civilian technology. Yet without regulatory changes, current performers of military R&D will have not incentive to improve their links to civil R&D. (p. 11)

- A decision to emphasize dual-use technologies or civil-military integration would require the DoD and the Services to increase reliance on commercial firms, provide incentives for using non-developmental items, and stress performance criteria over rigid military specifications. These policies would require greater initiative on the part of government contracting officers than is currently allowed, and therefore better trained government acquisition personnel. (p. 20)

From *Redesigning Defense* (1991):

- A recent OTA assessment of international arms cooperation noted that foreign defense firms in Europe and Japan are structured to make much more use of their civilian capabilities. This structure has resulted, at least in part, from different approaches to acquisition and accountability. (p. 13)

These findings suggest that, in order for a dual-use program to succeed, institutional considerations are as important, and perhaps more important, than technical ones.

B. PUBLIC SECTOR CHOICE OF TECHNOLOGY INVESTMENTS

Investment choice in the private sector is generally handled by the business community as one of many issues influencing the future profitability of an enterprise. Public sector investment choice, on the other hand, spans not only issues of profitability, but also those generally included in such social welfare estimations as employment levels, aggregate growth rates, industrial performance, and trade balance. In the public sector, such issues are the domain of the economist.

Over the past two centuries the economics profession has repeatedly explored how to rank preferences among different sets of social choices.[9] The result has been a set of formalisms and theorems that today constitute the "theory of choice." This theory seeks to uncover the logical foundations of "rational" decision making among alternatives or sets of alternatives that may be extended to help understand how to choose technologies and technology support activities in which to invest.

One approach, choosing among projects based solely on technical measures, even when such measures are in common, generally leads to ambiguous results. Selection

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9 This aspect of economics was examined at length by White and Tai June 1995, 65–104, and this section draws heavily upon that work.

activities that rely solely on technical merit therefore employ so-called experts who must make informed judgments in order to come to closure.

Technical characteristics are not the only possible evaluation dimensions of source selection processes. In the private sector the monetary requirements to carry out a project, and the expected returns, are also a basis on which to judge and rank. Such financial considerations form the basis for private sector assessments of a project's "private rate of return." Here the issue is the perceived value of the project relative to its funding requirements and risk.

How to make "sound" decisions on R&D investments in the private sector is treated in two different ways by the literature on technological choice. One way, strategic management, deals with the importance of the innovation process as it pertains to the overall management of competitive business enterprises and its ability to confer a competitive "edge." The second way involves detailed approaches that may be used to evaluate and compare different technology and R&D investment possibilities. Such models include simple cost-benefit ratios, applications of linear programming, portfolio analysis techniques, group decision-making paradigms, and structured hierarchy processes. (See Appendix E for references.)

When the private sector is not interested in undertaking a project because its "appropriable" rate of return is unattractive or it does not have proper corporate fit, it does not necessarily mean that the project is unattractive to society at large. The *net* importance of an investment for society as a whole, taking into account all benefits and costs, may be disproportionately larger or smaller than for private individuals. For public policy makers it is this social welfare "dimension" that is usually problematic, not only for measurement reasons, but because ideology enters the picture through contending claims about the efficacy and efficiency of the marketplace to adequately perform with or without government intervention.

While there are many tracts and treatises regarding the "optimal" approaches to choosing investments, private or public, in the case of dual-use technologies four sources stand out. *Beyond Spin-off* offers selection criteria for technology investments of a "pathbreaking" and "strategic" nature; *The Economics of Commercial Military Integration and Dual-Use Technology Investments* offers a set of criteria tailored specifically for dual-use; *The Government Role in Civilian Technology* approaches investment from the point of view of pre-competitive and generic technologies; and, the *National Flat Panel Display Initiative* offers the perspective of an ongoing dual-use effort.[10] We offer examples of the recommendations contained in these works here, and present relevant portions of all four lists in Appendix B:

From *Beyond Spinoff* (Alic et al. 1992):

- What are the principal technical goals or milestones against which success is to be judged? If economic or cost-effectiveness criteria are important, what are they? (p. 388)
- Who are the possible or likely winners and losers if the technical goals are achieved and the results are implemented on a significant scale? Have all the potential stakeholders been properly identified, particularly those that might be affected by externalities or spillovers if the technology should be deployed on a large scale? (p. 389)
- To what extent are the benefits "public goods" (nonappropriable to the innovating organization), and hence eligible for federal sharing of the costs of implementation and deployment beyond the original development and proof-of-principle? (p. 389)
- Does the applicant industry appear to have an adequate strategic plan, with defined goals and milestones that would result in sustained competitiveness, taking into account the likely response of its foreign rivals, and assuming adequate U.S. government policy response with respect to any nontechnological . . . ? (p. 387)
- What are the estimated benefits and penalties of including affiliates of foreign-based multinationals as members of the consortium or partnership eligible for U.S. government assistance? What, if any, criteria in the way of codes of conduct, structural characteristics, reciprocal national treatment by home government of foreign affiliates, and so forth, should be set for membership in consortia seeking U.S. government support? (p. 397)
- How, by whom, and how frequently should progress toward meeting the goals of a strategic technology investment be assessed? (p. 398)
- The initiative must be subject to sunset provisions and include clear measures of success to force and guide decisions about the continuing necessity of the initiative over the medium- to long-term. (pp. 2–3)

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[10] Most recently the considerations expressed in these reports were generally reaffirmed by the National Research Council in *Allocating Federal Funds for Science and Technology*, National Academy Press 1995.

From *National Flat Panel Display Initiative* (DoD 1994):

- The long-term objective of extending the government's financial commitment to pre-commercial R&D is to enhance U.S. productivity and raise its standard of living. To do this, support for R&D should be closely linked to commercial markets, as well as being in areas with the potential for wide industrial application. Projects to stimulate collaborative R&D ventures funded through government-industry partnerships should be proposed and structured by industry. (p. 117)

From *The Government Role in Civilian Technology* (National Research Council 1992):

- To ensure the market relevance of R&D funded by the government in cooperative ventures, participating private sector firms or institutions (except nonprofit organizations) should bear a significant share of program costs. In most cases, this would involve private firms covering on the order of 50 percent of the total program costs of any pre-commercial R&D or technology project. (p. 116)
- Projects funded under an expanded federal program should complement and not compete or interfere with pre-commercial R&D and technology development activities under way elsewhere in the federal government . . . . Diversification across projects by technology area is also essential to the success of an expanded federal program. (pp. 118–119)
- Political considerations should not influence R&D programs' technical output, the location of R&D facilities, or the management of R&D projects. (p. 118)

This list is by no means inclusive of all recommendations reviewed, and not all criteria set forth here are relevant to all situations. In the literature it is clear that there is no "single best" approach to constructing a technology investment portfolio, dual-use or otherwise. The process is complicated by significant difficulties in comparing the attributes of different investment possibilities, as well as by long time horizons that make it impossible to accurately predict their outcomes. Even retrospective assessments of prior technology investments are not always illuminating because of the myriad non-technological factors that may influence outcomes. We are thus led to rely on lessons from past investments to structure programs according to a priori beliefs in principles that will regulate their behavior and determine their performance.

C. LEGAL AND INSTITUTIONAL ISSUES

The current Defense acquisition system imposes heavy burdens on the conduct of government-funded development of dual-use technology, products, and processes. The rigidity of Defense contracting practices and many of the people who implement them can create a significant barrier against the participation of the best commercial research companies in dual-use research activities. A recent analysis compared a list of the 500 largest DoD RDT&E contractors (those receiving more than $2.3 million in 1993) with the 1994 Fortune 500 Industrials list and found that 91 percent of firms on the Fortune 500 list had insignificant or no DoD RDT&E awards. Conversely, 50 percent of 1993 RDT&E awards went to the top six Defense contractors, and 78 percent went to the top 20.[11] This analysis attributed the reluctance of R&D-intensive commercial companies to participate in DoD R&D in part to "overarching demands for intellectual property" and "other unique mandates."[12]

As noted above, the determining factor for successful exploitation of commercial developments for Defense purposes is the extent to which the DoD acquisition system is able to accommodate commercial approaches to doing business. Without such accommodation, the best commercial companies will continue to refuse to bother with doing business with DoD. The existing acquisition system fails this test in several key areas, all of which can be dealt with more flexibly using the "Other Transactions" authority that ARPA has had since 1989 (and that is described in more detail below). These key areas are:

- Excessive reliance on cost-reimbursement contracting methods
- Inflexibility in the allocation of intellectual property rights (chiefly patent rights, but also the other rights embodied in the acquisition system's concept of "technical data")
- Interference in contractors' relationships with subcontractors
- Certifications and burdensome regulations in general

1. Excessive Reliance on Cost-Reimbursement Contracting Methods

The DoD acquisition system is heavily invested in the concept of cost-reimbursement contracting. The mentality fostered by this investment requires that

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11 Spreng 1994.

12 Ibid.

expenditures in R&D projects be tracked in minute detail and accounted for so that fear of fraud, waste, or abuse can be completely allayed. This results in a set of acquisition rules once described (by Senator Jeff Bingaman of New Mexico) as spending thousands to save hundreds. It also creates a culture of mistrust between contracting officials and research performers that is inimical to good R&D. Specific aspects of the cost-reimbursement mentality that need to be addressed include:

- **Mandated, inflexible accounting systems, commercially inappropriate cost principles, and burdensome audit requirements.** Commercial firms have accounting systems that meet their *commercial* needs. These systems typically conform to GAAP—Generally Accepted Accounting Principles. The requirement that companies doing DoD-funded research conform to the cost accounting standards of the Federal Acquisition Regulation (FAR) can force a change of accounting system on an entire company, not just on the group or division conducting the sponsored research. Some companies have responded to this requirement by creating separate subsidiaries or divisions within their firm to do government-funded business. However, these separate business units are almost universally characterized by higher costs than their commercial counterparts.
- **Excessive demands for cost and pricing data mandated by the Truth in Negotiations Act (TINA).**[13] In large government acquisition activities,[14] proposers are required to provide detailed certified information about their costs and their methods for determining their prices. Commercial firms, in particular, find this both an administrative burden and an intrusion into their private business affairs.

2. Inflexible Allocation of Intellectual Property Rights

Patent rights in federal contracts, grants, and cooperative agreements are governed by the provisions of the Bayh-Dole Act.[15] Under Bayh-Dole, ownership of inventions conceived or first reduced to practice in the performance of a government contract rests with the inventor. The government receives a broad license to practice or have others practice the inventions for government purposes. In addition, the government has "march-in rights," which allow the government to license inventions to third parties if the owner does not take reasonable steps to commercialize the inventions in a reasonable

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[13] 10 U.S.C. § 2306a.

[14] The limit was recently raised in all cases to $500,000.

[15] 35 U.S.C. §§ 200-212.

time. While the Bayh-Dole allocation of patent rights is appropriate for many situations, it can interfere with commercialization efforts in others and preclude the protection of patentable inventions as trade secrets, the preferred course for many high technology companies, particularly those in the information industry.

The current FAR and Defense FAR Supplement (DFARS) regulations governing "technical data," a category that includes most computer software, are complex and obscure and fraught with obstacles that a contractor must deal with in order to avoid unintentionally delivering technical data to the Government with "unlimited rights."

3. Government Interference in Contractor-Subcontractor Relationships

The government's approach to contracting interferes with its contractors' supplier relationships in a number of ways.

- **Restrictions on choice of subcontractors.** Most negotiated government contracts include a provision, required by the FAR, that a contractor "shall select subcontractors (including suppliers) on a competitive basis to the maximum practical extent consistent with the objectives and requirements of the contract."[16] High-quality commercial R&D is characterized by the selection and development of long-term relationships with a set of reliable suppliers over time. The FAR's competition requirement, which is frequently imposed in R&D contracts whether its use is actually required or not, is antithetical to the maintenance of such relationships. At the very least, it invites argument between contractors and contract officers over whether competitive subcontracting is "consistent with the objectives and requirements of the contract" when such long-term relationships exist. There are also requirements that may apply in particular situations that favor subcontracting with minority businesses, labor surplus area businesses, or women-owned businesses.

  A second FAR requirement imposes advance notification to the contract officer and consent by the contract officer to significant subcontracts. The notice requirement can be burdensome and invasive because of the detailed information it requires about the relationship between contractor and subcontractor and because it may require certified cost and pricing data and

[16] The requirement applies to all contracts above the "simplified acquisition threshold"—currently $25,000, but increasing to $100,000 through implementation of the Federal Acquisition Streamlining Act of 1994—and is set forth at FAR § 44.204(e). The language is prescribed by FAR § 52.244-5.

certificates and disclosures by the subcontractor relating to cost accounting standards.[17]

- **Requirements that contract provisions "flow-down" to subcontractors.** Another burden on subcontracting is the requirement that certain provisions of the contract be included in all subcontracts. Such "flow-downs," like the requirement of certified cost and pricing data, are an undue and unwelcome burden on suppliers to contractors doing government-funded R&D, particularly when those suppliers do no government business of their own.
- **Restrictions on prime contractors' access to subcontractors' intellectual property.** Government policy prohibits contractors from using their ability to award subcontracts to acquire rights for themselves in their subcontractors' inventions. This policy results in the inclusion in government contracts of a clause that prohibits grant-backs to contractors of rights in subcontractor inventions. In the dual-use environment, such grant-backs may be at the heart of commercialization for the technology being developed.

4. Certifications and Burdensome Regulations

Doing business with the government requires a number of compliance certifications, although the number has decreased with enactment of the Federal Acquisition Streamlining Act of 1994. At a minimum, DoD components require representations and certifications relating to drug-free workplace requirements, debarment and suspension, lobbying, and nondiscrimination. While compliance with these certification requirements may not in itself be an undue burden, contracting with a party who requires such things is often regarded as burdensome by those not accustomed to doing business with the government.

In addition to certifications, DoD imposes detailed and burdensome requirements on, for example, employee time-keeping and on the handling and disposition of property that is either furnished by the government or purchased in the course of contract work with government funds.

5. DARPA Uses a Different Approach

DARPA has had the authority to enter into contractual arrangements called "Other Transactions" with its private sector R&D partners since 1989, and has used this authority widely in its dual use activities. Other Transaction agreements are characterized

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17 10 U.S.C. § 2306(e), FAR §§ 44.201-2, 52.244-2(b).

by enhanced flexibility (including flexible treatment of intellectual property) and reduced administrative burden when compared with the typical government procurement contract. Congress granted ARPA this "Agreements Authority" in recognition that a procurement contract is not the appropriate type of agreement for government-supported science and technology projects, a principle recognized in the FAR itself.[18] Grants and cooperative agreements are generally appropriate to support and stimulate public purposes like the advancement of science and technology. However, Congress has recognized that even the use of standard grants and cooperative agreements cannot provide sufficient flexibility for the needs of every research venture; hence the establishment of Other Transactions.[19] Conversely, however, not every research venture requires an Other Transaction; in many cases, especially those in which DoD's standard, legally mandated allocation of intellectual property rights is acceptable to all parties, and a cooperative agreement will serve the purpose.

D. ORGANIZING A DOD DUAL-USE PROGRAM

The prospects for developing a unified dual-use program in the Department of Defense hinge on the principles illuminated in the preceding discussions. From the outset it is important to recognize that the organization of the program may be less important than resolving fundamental differences in the perception of dual-use between the civilian leadership in the Department and the Armed Services.

Clearly, the greatest benefits to DoD in terms of overall capability, affordability, and timeliness will accrue from a spin-on approach to dual-use; such an approach seeks to leverage commercial efficiencies. Needless to say, this approach is not completely harmonized among all DoD stakeholders.

1. Policies for Organizing a Dual-Use Program

Let us assume that the fundamental differences in approaching dual-use between DoD civilian and military leadership are resolved and that one or more of the dual-use

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18 FAR § 35.003(a) reads: "Contracts shall be used only when the principal purpose is the acquisition of supplies or services for the direct benefit of the Federal Government. Grants or cooperative agreements should be used when the principal purpose is to stimulate or support research and development for another public purpose."

19 Despite this legislative recognition of the need for flexibility, there has been persistent misunderstanding of ARPA's use of Other Transactions from the time the enabling legislation was first enacted. For example, press reports have often mistakenly referred to Other Transactions as "grants."

program models introduced in Chapter 2 is chosen. Whatever organizational structures are chosen, the authors agree that they would need to adhere to the following principles, which derive from earlier discussions:

- **Identify investment opportunities.** A dual-use organization must promote the application of *commercial* technological opportunities to the needs/requirements of the future military.[20] This is not straightforward and requires that military program schedules and budgets be aligned with technological advances.[21]
- **Rank investment alternatives.** Echoing a recent study by the National Academies, "[d]epartments and agencies should make [investment] allocation decisions based upon clearly articulated criteria that are congruent with those used by the Executive Office of the President and by Congress."[22] For dual-use this means resolving the differences of opinion regarding the meaning of such investments at a high level, and then enforcing this view to overcome parochialisms that might lead to simply dividing-up funding or channeling efforts to areas outside the scope of national policy.
- **Operate outside of the current Federal Acquisition Regulations (FAR).** "Fundamental reform of the defense acquisition system is the essential foundation for DoD's dual-use technology strategy."[23] To facilitate its operation and afford flexibility, ideally a dual-use program would operate outside of the umbrella of the FAR. This is because the FAR discourages the participation of the very commercial companies that would be most beneficial to the military in the program. Furthermore, to the extent possible contracts should be written so that they conform to commercial standards and norms and not to those of traditional government procurement procedures.[24]
- **Assess commercial market opportunities.** A dual-use program must be capable of independently assessing commercial market opportunities and understanding commercial businesses. This means that when it comes to investment decisions, considerable if not equal weight should be given to

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20 Executive Office of the President 9 February 1995, p. 2.

21 White and Tai June 1995, 16–18.

22 National Research Council 1995, 10.

23 Executive Office of the President 9 February 1995, 3.

24 U.S. Congress, Office of Technology Assessment 1994, 74. See also Perry 1994, 8.

technical and business characteristics of proposed activities. This may require retaining outside expertise or developing in-house capabilities.[25]

- **Adjust subsidy levels.** When subsidizing commercial firms, the level of subsidy should be scaled and adjusted to encourage participation while minimizing government outlays. This means that a program should be designed to allow such subsidies to vary according to risk and the level of interest on the part of DoD.[26]

2. Possible Organizational Models

Generally, the literature discusses the programmatic goals for dual-use efforts and principles for their conduct rather than specific organizational models. We therefore address this issue by offering three intellectual constructs that could be used to guide a dual-use program based upon the authors' experiences with the TRP, and briefly remark on how these might be used to manage both political realities and commercial exigencies. We consider the advantages of operating the program on the basis of a brokered approach, consensus-driven approach, or externally-driven agenda. The five preceding principles would be handled differently for each of these.

- **A brokered program.** A brokered approach would place one party in the position of overseeing trade-offs among the different benefactors from the program. Success would be a function of the participants perceiving the broker to be honest and fair. Investment areas would be nominated by the participants and selected by the broker. As such, the broker would need to have an independent assessment capability to determine the best opportunities. Competition, awards, and contract negotiations, including level of subsidies, would be handled by a joint program office, while the assessment of commercial opportunities could be done internally by this office or contracted-out.

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25 Here we have adapted one of the findings in *The Government Role in Civilian Technology*: "Evaluations of competing R&D proposals—either by a single firm or by groups of firms in a collaborative venture—that might be sponsored under an expanded federal program should be conducted by independent experts in the relevant scientific, technological, and economic areas." National Research Council 1992, 118.

26 This conclusion is based on the following finding in *The Government Role in Civilian Technology*: "To ensure the market relevance of R&D funded by the government in cooperative ventures, participating private sector firms or institutions (except nonprofit organizations) should bear a significant share of program costs. In most cases, this would involve private firms covering on the order of 50 percent of the total program costs of any pre-commercial R&D or technology project." National Research Council 1992, 116.

- **A consensus-driven program.** A consensus program would operate somewhat like the brokered approach, but trade-offs would be done based on the mutual agreement of all parties involved—there would be no arbitration process. Investment areas would be selected based on consensus, and competitions could be carried out collectively or through a joint program office. Administrative functions, such as awards and contract negotiations, would be handled by a joint program office, while again the assessment of commercial opportunities would be handled as in the brokered scenario.
- **An externally driven agenda.** This approach is reminiscent of top-down planning, and would rely upon brute force to dictate the conduct of the program. It is the least favorable implementation for dual-use since it fosters a competitive atmosphere and removes authority from the purview of the program manager. Conversely, if differences in interpreting the goals of dual-use persist, an externally driven agenda may be required to allocate resources according to high-level policies. A joint program office could also be employed to manage such a programmatic approach.

3. Unified or Distributed Program Operation

The decision to operate a DoD dual-use program on a unified or Service-distributed basis rests heavily on the definition of dual-use. Given the oft noted disparity in the DoD civilian and military leaderships' views on dual-use, one could argue that distributing the program among the Services, and their R&D arms, might continue the pursuit of COTS and spin-off approaches.

On the positive side, a dual-use program distributed across the Services would generate greater organizational ownership and less resistance to new ideas. Also, administrative procedures need not be modified to meet the requirements of an external entity, and contracting approaches would be more easily harmonized.

On the negative side, distributing DoD's dual-use program across the Services would—

- Encourage parochial investments and increase the likelihood of duplication of effort.
- Complicate, if not preclude, presenting a harmonized and unified vision of dual-use to Congress.
- Encourage different approaches to contracting and risk losing the benefits of such instruments as Other Transactions Authorities.

- Encourage participating firms to submit the same or similar proposals to each program, making work loads higher than otherwise necessary.
- Risk losing opportunities for organizational economies of scale.

4. Non-DoD Agency Participation in the Program

The TRP allowed civil agencies to participate in the selection, management, and oversight of dual-use projects. These agencies' knowledge of their respective commercial markets was an attractive incentive, but their participation in the TRP made the program very difficult to sell to a Republican Congress. The new leadership on the Hill argued that including civil agencies created the apparent, if not de facto, use of DoD monies to fund non-DoD missions.

While the civil agencies involved did have some understanding of the technology investment opportunities in the commercial world, it now appears that their information was generally insufficient to assist TRP decision makers in determining where the greatest commercial leverage would be in competing projects. This occurred for three reasons:

- Unless a civil agency is already deeply involved in supporting commercial activities, its personnel generally have no better reading of the commercial opportunities than do DoD personnel. Recognizing this fact, the Department of Commerce's ATP program employs outside business experts to evaluate proposals for their market potential, even though the agency is an arm of the nation's economic and statistical organization.[27] And after studying the role of government in civilian technology the National Research Council recommended using outside, objective expertise when evaluating proposals.[28]
- The personnel supplied to assess commercial business prospects for proposed technologies were drawn from the acquisition and procurement side of the civil agencies, and most were ill equipped for this task.
- It is well known that technical personnel are subject to parochial agendas regardless of their organizational affiliation.[29] When these agendas vary

[27] "Independent business experts are also hired on a consulting basis. These business experts include high-tech venture capitalists, people who teach strategic business planning, and retired corporate executives from large and small high-tech businesses in the subject area of competition." U.S. Department of Commerce (1994), 6.

[28] National Research Council 1992, 118.

[29] White, Stowsky, and Hauger September 1995, 20–24.

from the needs of the Department of Defense, they may lead to project evaluations that bias the selection of proposals for funding.

These reasons argue forcefully against allowing civil agencies to participate directly in the guidance of DoD dual-use programs and in the evaluation and selection of proposals on a business basis. Nevertheless, the technical expertise of civil agencies may be very useful, and their organizational capabilities warrant their continued consideration in a project management role once proposal awards have been made.

5. Possible Strategies for Soliciting and Selecting Proposals

Based on the materials reviewed, little criticism can be leveled at the existing TRP strategy for soliciting and selecting proposals. In fact, this issue has received precious little attention in the dual-use literature. Based upon our own experience, we offer the following principles (which have generally been in place at the TRP) for future dual-use solicitations:

- **Ensure that the process is perceived to be fair**. A solicitation process must not only be fair, it must be *perceived* as such. Thus, the procedures and rules for selection must be well documented in order to withstand audits and challenges.
- **Solicit widely**. The first round of the TRP may be the archetypal approach to outreach for a government program. It included high-level government announcements, regional seminars and presentations, and publication of notices in the *Commerce Business Daily* and *Federal Register*.
- **Establish internally consistent selection procedures**. In general, the procedures used to select proposals should follow basic choice principles, as laid out, for instance, in *The Economics of Commercial-Military Integration*.[30]
- **Announce awards promptly**. Once the selection of proposals is finalized, the announcement of awards should be swift and widely disseminated.

6. Use of Consortia

Originally, the notion behind requiring consortia, or partnerships as they are termed in TRP legislation, was to ensure that the entities funded were pre-competitive. As discussed earlier, the notion of pre-competitive was introduced by the Bush

30 White and Tai September 1995, 65–104.

administration as a means of justifying government support for private sector technology endeavors. The idea is that by requiring a significant portion of the firms within an industry to agree on the type and subject of collaboration, all investments ultimately made on a joint basis will be mutually beneficial and will not confer a competitive advantage on any one firm. In our earlier discussion of consortia (Chapter 4), however, we pointed out that such investments must also be structured so as to avoid collusive behavior on the part of the participants as well as to address issues of mutual interest.

Based upon our findings in Chapter 4, we conclude that only two primary types of consortia are suitable for dual-use, and each of these may be structured in two different ways. The first type, the government-industry consortium, is essentially the alliance of a government agency, laboratory, or other government entity with one or more private firms. The second type, the industry-industry consortium, can involve various types of firms, but in the case of TRP and dual-use the optimal alliance is between a defense and commercial firm. Each of these types of consortia may be structured either horizontally or vertically. In horizontal consortia, participating firms come from the same industry and regard each other as competitors. In vertical consortia, participating firms come from different industries and have buyer-supplier type relationships with each other that cause them to regard each other as natural collaborators.

Rather than attempting blanket statements about the efficacy or desirability of one type of consortium over another, or whether they should even be allowed, we offer some key questions that may be used to assess whether the consortium form of business is in fact applicable:

- **Is the objective achievable without collaborative activities?** Goals are usually pursued jointly when the collaborators individually lack the know-how or resources to proceed alone, or because there is a mutual desire to defray risk and reduce individual resource commitments. If the objectives are otherwise achievable then a consortium should be regarded as an option to be used when it improves the overall chances for positive results or otherwise improves the performance of the activities undertaken.
- **Is collusive behavior anticipated?** If the government seeks to use the consortium approach, it must realize that this may afford one set of firms an advantage over another or may promote otherwise collusive behavior. This is part of the pre-competitive issue: Should government be in the business of creating advantages for selective firms or combinations of firms? One answer is that government has always done so through its contracting with private firms; the real issue, then, is fairness in competition and award, not

the form of organization. Conversely, one could argue that the government should avoid enabling collusive activities that may diminish the competitiveness of firms not involved in an activity, particularly activities that would be in clear violation of anti-trust laws.

- **Do we want the results to be available to a larger group than the principal investigators?** If the goal of a research project is to make the results available to many firms, a consortium may be the best vehicle. The issue becomes the entry barriers to joining the consortium, such as high membership fees, or the possible control of results by a small subset of the participants. In the case of membership dues, government can seek to defray these for smaller firms, while in the case of intellectual property control and ownership, the issue is one of negotiating access up front and leaving little to imagination or chance.
- **Will the results offer a single firm a significant competitive advantage?** In some cases, an investment by the government can confer a significant competitive advantage to a firm. While this may not last in the long run, one is led to ask whether the creation of, say, a temporary monopoly is the most advantageous approach for society as a whole. Oddly enough, the answer may be yes in two broad cases: 1) if the investment costs are considerable, monopoly rents (profits) may be warranted to advance a new technology or capability through scale or scope economies; 2) if there are large foreign competitors, the promotion of national champions may be warranted to achieved the scale necessary to be globally competitive.
- **Are there overriding national interests involved?** There may be cases in which the national interest is at stake, and in this case the rationale is extra-market and the issue of consortia is moot.

7. Advantages and Disadvantages of Government Cost Sharing

The rationale for cost sharing is that by requiring the private sector to put up a portion of the funding necessary to undertake a venture, the government ensures that there is commercial, or at least industry, interest in the venture. After all, why would a firm engage in a venture with its own funds if it did not have a long-term interest in the results? On the other hand, one could argue that this logic is flawed for the following reasons:

- When a project is proposed to the government, there is no means of validating that it would not have otherwise been done. As such, the use of government monies may simply be to augment the firm's bottom line—a subsidy.

- Even if the funding is used on a project, the fact that funding is "liquid" makes it possible for a firm to use the funds for projects other than the one targeted. This happens when a firm proposes its most attractive projects, ones which it would have done anyway, and "flows" the government subsidy into other activities that it lacked the money to pursue.
- It is clearly possible for the unit of a firm, one which is not receiving sufficient funding already, to submit a winning proposal and use the funds simply to avoid layoffs or facility closures.

On the other hand, one could argue that government cost sharing may be useful for the following reasons:

- It could lead to the collaboration of firms not otherwise disposed to work together. In this case the corporate contributions represent real commitments to a consortium because they place each participant at risk. The government share is then viewed as a way to defray or reduce the overall risks of collaboration which cannot be justified on a company by company basis.
- By requiring firms to put up part of the costs of a project, the government is able to defray some of its own costs of pursuing an activity.
- Money (cash) means that the parties have a real and demonstrated interest, and are committed to producing a return on their investment.

8. Strategies for Handling Intellectual Property

Prior to the enactment of the Bayh-Dole Act[31] in 1980, the general rule for intellectual property created with government funding was "the government paid for it, so the government owns it." This policy did little to encourage commercial use of government-funded inventions because it left all the significant rights in those inventions in the hands of the government, an institution clearly unsuited to commercializing technology. The Bayh-Dole Act brought a uniform and enlightened policy on allocation of patent rights to universities and small businesses conducting government-supported research. In 1983, a presidential memorandum extended the Act's policy to large businesses.

The allocation of intellectual property rights should reflect a balancing of the relative needs and previous investments of project participants. If industry has expended large sums over time to advance the state of the art in some technology with little or no

[31] 35 U.S.C. §§ 200–212.

government support, then the government should be willing to allow industry to maintain a proprietary position. This is especially true where the government's interests are best served by having the technology employed in products that are available in the commercial marketplace.

Bayh-Dole allows inventors to retain title to inventions conceived or first actually reduced to practice under government funding. The government obtains a paid-up, worldwide license to use each such invention for government purposes, including competitive procurement. The government also has march-in rights, which allow it to license the invention to some third party for commercial purposes if the patent owner fails to take reasonable steps to achieve practical application or if other specified conditions occur. There are specified administrative procedures relating to invention disclosure and election to retain title by the inventor. A consequence of these procedures is that an invention may be maintained as a trade secret for a relatively brief period before the inventor-owner must either file a patent application or allow ownership to vest in the government.

The purpose of the Bayh-Dole Act's allocation of rights was to promote commercial use of inventions created with government support while giving the government certain "protective" rights. To a degree, this purpose has been achieved. However, some developments since 1980 have not fit well within the Act's framework. Problems have arisen with R&D joint ventures involving both government contractors and commercial firms. Commercially available technology has outpaced Defense technology in a number of areas. The Cold War came to an end, and the defense market has shrunk to the point that defense contractors must become "more commercial" if they are to survive. Because of these and other factors, the Bayh-Dole allocation of patent rights is no longer adequate in all cases in which the government enters into R&D relationships with commercial firms or in which government contractors want to move into commercial business.

Fortunately, by its own terms, the Bayh-Dole Act applies only to procurement contracts, grants, and cooperative agreements.[32] ARPA and the Military Services have the authority to enter into agreements that are none of these and under which patent rights regimes that differ from that mandated by Bayh-Dole can be crafted to meet the needs of

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[32] The Act applies to what it calls "funding agreements," a term which it defines as "a contract, grant, or cooperative agreement."

the parties. While more extreme deviations are possible where their need can be adequately demonstrated in the context of the private parties' commercialization plans, the most common alterations to the customary scheme have been to delay the effective date of the government's license, to specifically define what actions constitute reasonable efforts to commercialize, and to delay the exercise of march-in rights. Such measures reduce the actual and perceived risk to the private sector participants. It has also proven helpful to draft explicit provisions excluding previously-conceived inventions (so-called background technology) from the scope of any government license.

Similar considerations—and solutions—apply to other intellectual property rights (copyright, trade secret, and—rarely—trademark). ARPA typically takes steps to minimize the actual delivery of contractor data to the government so that proprietary information never becomes an "agency record" and is not, therefore, subject to disclosure in response to Freedom of Information Act requests. Instead of requiring delivery of sensitive data, ARPA instead uses meetings, briefings, off-site reviews, and delivery of summary reports.

The goals of a particular project, not some cookie-cutter approach based on overly broad rules, should therefore define the appropriate allocation of rights among consenting parties in a collaborative venture. Bayh-Dole offers such flexibility, and the exercise of its provisions should be considered integral to the functioning and policy perspectives of any dual-use program instituted, regardless of the specific model chosen.

9. Foreign Participation in Dual-Use Projects

The TRP provided for the inclusion of foreign entities on project teams. The primary limitation was to be so-called reciprocal treatment, whereby a foreign nation's participating entity would have to offer U.S. entities similar access to that country's programs. This notion originates from trade negotiations among nations and seeks to prevent the firms of one country from benefiting from foreign government largesse without similar opportunities being afforded their international rivals. While the concept of reciprocity is widely embraced, U.S. government-sponsored technology programs should not exclude a foreign entity from participating without considering the following realities:

- **Today we live in a global economy.** We are unlikely to successfully control the availability of technological opportunity to our allies or adversaries on a long-term basis, particularly since much of the Cold War export control apparatuses have been or are being dismantled.[33] In all probability, what is useful for the U.S. may also be "dual-useful" to our adversaries as well as our allies.

- **Technology proliferation is a two-way street.** DoD may benefit from the adoption of foreign technologies, and foreign firms and militaries may benefit from adoption of U.S. technologies. Dual-use technologies available for commercial applications may therefore be spun-on by adversaries for military purposes.[34]
- **Technology is seen as a bargaining chip.** Access to advanced technologies is becoming less and less difficult, and some governments see the transfer of military technologies as part of overall economic and trade negotiations, perhaps even a means of "sweetening the pot."[35]
- **Firms are becoming ever more international.** With multinational enterprises, as noted by the Office of Technology Assessment, it is now even more difficult to make sure that U.S. technology does not migrate: "In sharp contrast to other advanced industrial nations, the United States typically exports five times more technology than it imports."[36] U.S. firms with foreign subsidiaries, and foreign firms operating in the U.S., have increasing access to a host of proprietary technologies. International collaborative research and development ventures make technology migration an even more likely possibility.

Clearly, today it is more difficult than ever to control the use or international migration of technologies once they are in the hands of commercial firms. This suggests both benefits and costs from the participation of foreign entities in U.S. dual-use technology programs. On the one hand, an advantage from participation may accrue to the U.S. military since commercial technologies are ahead of many military technologies today. As such, their rapid advance would be beneficial for the U.S., assuming that they can be spun-on by the U.S. faster than its adversaries. On the other hand, the proliferation of militarily useful commercial technologies allows adversaries the opportunity to take advantage of the most advanced capabilities available worldwide.

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33 National Academy of Engineering 1991, 2.

34 Refer to our earlier discussion of the FS-X program in Chapter 6, and see also: Office of Technology Assessment May 1990, 3–5.

35 Ibid.

36 Office of Technology Assessment September 1994, 2.

A prudent strategy would be to strike a balance within a dual-use program and, on a technology area basis, seek to include or exclude foreign participation based upon ultimate military goals and utility. This strategy could be justified by pursuing dual-use on two levels, one seeking to spin-on commercial technologies for general military benefits, and the other seeking to build upon commercial technologies to advance the military (and perhaps also commercial) state of the art.

E. SUMMARY

- Dual-use investment is but a small part of aggregate DoD program investment activities, as discussed in Chapter 2, and despite the increasingly dual-use nature of many technologies, defense-specific production activities are still the norm. DoD could, however, seek to reduce the differences between the process technologies employed in the production of military and commercial systems to take advantage of commercial economies of scale and scope, as well as other efficiencies. Some products could be co-produced in the same facilities and, in some cases, on the same production lines. In that eventuality the performance of a greater number of commercial sectors of the economy would become "directly" defense relevant.
- The economics of dual-use demonstrates that government must make it worthwhile for commercial firms in the private sector to do business with DoD. But the government must take care not to upset the balance of the marketplace through its actions. Particularly in cases where strong scale or scope opportunities are likely, the government must avoid driving out competition by giving any one firm an edge over another. The purpose of dual-use is to take advantage of efficiencies spawned in a competitive marketplace, not to create inefficiencies through ham-handed policies and inadvertent monopolies. These findings suggest that in order for a dual-use program to succeed, institutional considerations are as important, and perhaps more important, than technical ones.
- In the literature it is clear that there is no "single best" approach to constructing a technology investment portfolio, dual-use or otherwise. The process is complicated by significant difficulties in comparing the attributes of different investment possibilities, as well as by long time horizons that make it impossible to accurately predict their outcomes. Even retrospective assessments of prior technology investments are not always illuminating because of the myriad non-technological factors that may influence outcomes. We are thus led to rely on lessons from past investments to structure programs according to a priori beliefs in principles that will regulate their behavior and determine their performance.

- Clearly, the greatest benefits to DoD in terms of overall capability, affordability, and timeliness will accrue from a spin-on approach to dual-use; such an approach seeks to leverage commercial efficiencies. Needless to say, this approach is not completely harmonized among all DoD stakeholders.
  - Policies for organizing a dual-use program should include a means for clearly identifying military needs and corresponding commercial opportunities; an explicit investment ranking methodology; operation outside of the FAR; independent means for assessing commercial market opportunities; and flexible cost sharing.
  - Three general organizational models would be amenable to dual-use programs. A brokered program that would place one party in control as program manager with the authority to arbitrate investment selections; a consensus-driven program that would require all parties to agree to investment area selections; and an externally driven program that would select technology investments in a top-down fashion according to its own agenda. In all cases a joint program office approach would be useful.
  - To ameliorate a variety of negative institutional side effects, a DoD dual-use program would best be executed on a unified basis. This would avoid parochial investments, improve program appearance to Congress, discourage different contracting approaches for dual-use, prevent duplication of proposal submission, and open opportunities for programmatic economies of scale.
  - A variety of reasons argue forcefully against allowing civil agencies to participate directly in the guidance of DoD dual-use programs and in the evaluation and selection of proposals on a business basis. Nevertheless, the technical expertise of civil agencies may be very useful, and their organizational capabilities warrant their continued consideration in a project management role once proposal awards have been made.
  - The process for soliciting and selecting proposals should be perceived as fair, have wide outreach, include internally consistent selection procedures, and culminate in the prompt announcement of awards.
  - The use of consortia to pursue dual-use should be based upon the goals of the program. Key considerations include whether objectives are achievable without collaborative activities, collusive behavior of participants is expected, results will need to be available to a group larger than that of the principal investigators, results will give a single firm an undue or unfair advantage in the marketplace, and overriding national interests are involved.

- The rationale for cost sharing is that by requiring the private sector to put up a portion of the funding necessary to undertake a venture, the government ensures that there is commercial, or at least industry, interest in the venture. Conversely, cost sharing does not necessarily filter out projects that would not have otherwise been undertaken, it does not prevent firms from proposing their "best" projects and reallocating funds to projects of lower priority after awards have been made, and it does not preclude the use of funds simply to avoid layoffs and plant closings. Still, cost sharing could lead to the collaboration of firms that otherwise would not work together, it defrays some of the government's cost of doing business, and cash requirements tend to elicit real commitments from the private sector.
- Strategies for handling intellectual property tend to revolve around the Bayh-Dole act of 1980, which brought a uniform and enlightened policy on allocation of patent rights to universities and small businesses conducting government-supported research. The allocation of intellectual property rights should reflect a balancing of the relative needs and previous investments of project participants. The goals of a particular project, not some cookie-cutter approach based on overly broad rules, should therefore define the appropriate allocation of rights among consenting parties in a collaborative venture. Bayh-Dole offers such flexibility, and the exercise of its provisions should be considered integral to the functioning and policy perspectives of any dual-use program instituted, regardless of the specific model chosen.
- Foreign entities should be excluded from U.S. government sponsored dual-use projects only after thorough consideration of the ramifications of such policies in a global economy. Since technology is now a two-way street and firms are becoming more international, the flow of technological know-how is not really controllable without disrupting overarching trade and enterprise policies. A prudent strategy would be to strike a balance within a dual-use program and, on a technology area basis, seek to include or exclude foreign participation based upon ultimate military goals and utility.

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VIII. FINDINGS

For this paper we were asked to address five questions regarding the structure and operation of a DoD-led dual-use program as a follow-on to the TRP and in support of expressed DoD dual-use goals. The approach we chose was to review the history of dual-use efforts and debates and then apply lessons learned to programmatic considerations. In this chapter we respond to the questions and offer four overarching conclusions pertaining to the efficacy of pursuing increased military reliance on the commercial industrial base.

A. BROAD CONCLUSIONS

CONCLUSION: No single approach to pursuing dual-use simultaneously satisfies all government stakeholder constituencies. Rather, four distinct models of dual-use programs may be defined based upon historical experiences: purposeful spin-off, direct spin-on, indirect spin-on, and industrial base strengthening. Each model sets as its goal the promotion of dual-use capabilities, but the means for pursuing this goal differs considerably among the models.

From the outset, this paper adopted a generic definition of dual-use without allying itself with any one specific approach to pursuing its goal of increased commonality among commercial and military capabilities. That is, *dual-use refers to a product,*[1] *process, or technology that satisfies military needs while also exhibiting commercial viability in the competitive marketplace.* Based on our review of the literature and historical experience, we concluded that there is no objective method for validating any one approach as most efficacious. Rather, we proposed "optics" with which to assess the context in which the term was being used, and defined four different programmatic models which together spanned the set of activities historically termed dual-use.

Because of the implications for government agencies and their programs, understandably the term "dual-use" has itself taken on a political dimension. As a result,

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[1] The products category includes services.

it is interpreted differently based upon the stakeholder community involved. As examples, we pointed to the use of the term by the following constituencies:

- *Clinton White House.* Dual-use investments are made to pursue both economic growth and military capabilities. Early on, the administration emphasized economic growth; later, facing a Republican Congress, it emphasized military capabilities.
- *Democratic Congress.* Historically, key aspects of dual-use have included economic benefits from military spending, the spin-off of defense technology for commercial use, defense conversion, and employment.
- *Republican Congress.* Because of its ideological predisposition toward market-led solutions for economic problems, and the belief that the use of defense spending for activities not directly linked to Defense is wasteful, this constituency sees dual-use as pork.
- *Services.* Mission requirements and the structure of the military Services lead to a definition of dual-use in which commercial adoption of defense technologies and the military use of COTS and NDI are seen as the most beneficial applications of dual-use investments. This appears to originate from the top-down, requirements-driven approach to military R&D which has traditionally sought to maximize capabilities and minimize time to fielding.
- *Service Laboratories.* The spin-off of technologies for commercial use is seen as a means of validating and continuing the existence of ongoing R&D functions that may no longer be necessary due to the end of the Cold War.
- *Civil Agencies.* Because of the increased scrutiny of all federal R&D expenditures, civil agencies feel a need to find new ways to demonstrate that their programs have socially relevant outcomes. By adopting their own definition of dual-use—the commercial adoption of civilian R&D results—they hope to bolster their arguments and slow the anticipated decline in discretionary, non-defense R&D.
- *DoD Civilian Leadership.* Based upon its own experience in industry, the current civilian leadership of DoD sees dual-use as the spin-on of commercial technologies and co-production of products. Note that this effectively contradicts the notion held by the Service Laboratories, making for potential tension in any future dual-use technology initiatives.

Based upon these different visions for implementing dual-use programs, we defined four models, each of which has been validated as a suitable approach to achieving increased commercial and military commonality in the past.

1) *Purposeful Spin-off*: Intentionally funding activities that seek commercial applications for defense capabilities.

2) *Direct Spin-on*: The adoption of commercial off-the-shelf (COTS) capabilities and non-developmental items (NDIs) to meet the needs of the military.

3) *Indirect Spin-on*: Funding activities in the commercial sector to influence their development into capabilities which jointly meet the needs of the military and commercial sectors.

4) *Industrial Base Strengthening*: Addresses the broader role of the commercial industrial base and its importance to overall national security, both military and economic.

Based upon the historical examples reviewed in this paper, we conclude that any of these models makes for good public policy, and that the real issue is the underlying set of objectives for promoting dual-use, such as increased government-industry collaboration, commercial-military co-production, or direct commercial sourcing (COTS and NDI).

CONCLUSION: To enable a government program to successfully pursue dual-use objectives the acquisition system must be made more flexible and open to the notion of government-industry collaboration. This is not just a matter of formal regulations, directives, and instructions, but includes the need to reeducate and retrain acquisition officials so that they become more flexible in their interpretation of the FAR.

We have offered numerous observations on the issues of industrial base integration, dual-use investment criteria, the efficacy of consortia, and legal impediments to government-industry collaboration. To quote James Hughes of Westinghouse:

> [U]nique DoD/government procurement policies, practices and cultures, and politics are the show stoppers. Technology is not the problem. Numerous studies have urged the integration of commercial and military technologies. Constraints on contractors increased substantially throughout the 1980s which is very interesting, because everyone else was being deregulated. And the rather obvious observation is that if procurement practice reform had been acted upon as much as it has been talked about, we probably wouldn't be discussing it right now.[2]

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2 Hughes (1987) *Dual-Use Study*, edited by Kelly M. Curtis, John D. Geron, Mary K. Lamb, and Darlene Tawiah (Washington, D.C.: Electronics Industry Association), 236.

Based on our research, we concur and observe the following.

The development of dual-use technologies does not guarantee a transition path to military use or commercial markets. This is true for two independent reasons. First, some risk attends all development projects: the probability of reaching final goals is inversely proportional to the time required to reach these goals; it varies directly with management abilities and resources committed. Second, to reach both military and commercial goals through the same initiative may require a degree of compromise not acceptable to either the military or the commercial participants in a project. In both cases, however, dual-use approaches could considerably improve chances for project success over traditional military-go-it-alone approaches since a wider range of solutions and greater latitude and flexibility in approach become available. However, within the traditional acquisition system such potential advantages are easily negated when rules are narrowly interpreted.

A second consideration important from a dual-use perspective is that the timing of military and commercial product development cycles is not generally in phase. This problem is again institutional rather than technical because it centers not only on the turnover of technology, but also on the ability of the military to afford to replace its legacy investments in hardware, software, and training. As such, weapon systems that have long development lead times are retained in use even longer! There are dual-use strategies that could be used to address this issue on a component basis, such as rapid pre-planned product improvement with commercially and dual-produced items, but this again will require that planning within the acquisition system, particularly within the budget cycle, become more flexible to take advantage of emerging commercial capabilities that offer dual-use opportunities.

Therefore, while many budget-driven considerations remain, it is still important to ask, Without acquisition reform how would one pursue dual-use? This question is still valid, in our view, not only because the use of commercial components, practices, and approaches is constrained by a bureaucratic and legalistic framework that is abhorrent to commercial firms and inimical to commercial best practices, but also because many in the acquisition community continue to narrowly interpret acquisition rules.

CONCLUSION: Ideology is an unfortunate factor in the dual-use debate, making it inseparable from broader industrial policy issues. Whenever dual-use issues arise, they are assessed not only from objective perspectives, e.g., "does it help the military" or "is it good economic

> policy," but also from the perspective of parochial issues far afield of those involving national interest.

By their very nature, successful dual-use programs will require close collaboration of government and industry—the closer the collaboration the more likely that both military and commercial goals will be met. Such collaboration may be viewed as collusion by firms that are not fortunate enough to participate in dual-use programs. These firms will argue that government is upsetting a "balanced playing field," and that dual-use programs are not required. In fact, the TRP appears to have elicited such a reaction from some large defense firms. Behind this reaction lies the fear that commercial firms will begin to erode what was once the exclusive domain of defense contractors.

To bring a formal dual-use program to fruition and to entice commercial firms to participate, the government will need to offer risk reducing subsidies to industry participants. Firms face considerable risk in reallocating resources to take advantage of any opportunity, and dual-use is not inherently attractive for commercial firms. The solution is not as simple as it seems, however, because subsidies, termed "corporate welfare" by some in Congress, are thought to both unfairly assist the bottom line of "hand-picked" recipients and upset the normal functioning of the marketplace.

Another consideration is the ability to "enforce" dual-use once a technology or product has been developed. There is no guarantee that a commercial firm will be interested in pursuing the military side of an opportunity, and the only real way to assure this is to offer a rate of return on military production at least equal to what could be secured through commercial sales. DoD policies currently prevent firms from earning "excessive profits," and there is therefore no way to ensure that industry's interests will coincide with those of government once direct government funding of a development project has ended.

Finally, dual-use raises the general issue of the appropriate role of government in furthering the interests of private enterprises. As noted in Chapter 3, under the Bush administration a de facto compromise was reached that restricted government programs to funding pre-competitive and generic technologies. Under the Clinton administration the government role was broadened to include helping firms to actually compete in the global marketplace through technology subsidies. With constantly shifting political winds in U.S. politics, there needs to be bi-partisan agreement on how the government can consistently invest in the public interest without substituting for or competing with market forces.

CONCLUSION: That we live in a global economy is today a common theme. The implication for dual-use technology policies is that what is useful for the U.S. may also be "dual-useful" to our adversaries as well as our allies. Technology proliferation is a two-way street. DoD benefits from adopting foreign technologies, and foreign firms and militaries benefit from adopting U.S. technologies. Dual-use technologies available for commercial applications may be spun-on by adversaries for military purposes.

During the Cold War, the United States and its allies participated in the COCOM regime restricting the export/reexport of technologies that could offer a potential military edge to communist states. Since the end of the Cold War, such restrictions have been relaxed, and our allies have become even more liberal in their interpretation of what might not be harmful to international security. Access to advanced technologies is becoming less and less difficult, and some governments see the transfer of military technologies as part of overall economic and trade negotiations, perhaps even a means of "sweetening the pot."

With multinational enterprises, as noted by the Office of Technology Assessment, it is now even more difficult to make sure that technologies do not "migrate." U.S. firms with foreign subsidiaries, and foreign firms operating in the United States, have increasing access to a host of proprietary technologies. International collaborative research and development ventures make technology migration a real possibility.

Under such circumstances, it is difficult to control the use or application of technologies once they are in the hands of commercial firms. But since commercial technologies are ahead of many military technologies today, their rapid advance can be seen as beneficial for the U.S. military—assuming that they can be spun-on by the U.S. faster than its adversaries.

B. SPECIFIC FINDINGS

1. Potential Benefits From Dual-Use for the Military

CONCLUSION: The primary military benefits from dual-use are more affordable weapons and systems, timely insertion and adoption of cutting-edge technologies to rapidly enhance operational capabilities, greater industrial base flexibility fostering rapid supply-chain response to surge and sustainment needs in time of conflict, and domestic retention of strategic industries.

Incorporation of dual-use into military capabilities offers the potential for DoD to leverage the cost advantages available to the commercial world which accrue through economies of scale and scope. In particular, co-production of commercial and military items on the same production lines, the insertion of COTS items directly into weapons and systems, and increased reliance on NDIs, all potentially offer considerable savings over the development of military-unique capabilities.

Reliance on commercial capabilities also means that as commercial technologies race ahead, particularly in areas such as electronics, computing, telecommunications, and information systems, DoD will be more able to keep pace with cutting-edge developments in these areas. In particular, the greatest advantage will come if DoD improves the time to fielding of systems incorporating dual-use advances as this immediately improves the warfighting ability of U.S. forces worldwide.

Dual-use should also be encouraged down the so-called "supplier chain" which provides the raw materials and intermediate products which are necessary to develop, produce, and field weapons and systems. In this case the goal is to reduce the overall cycle time required to build-up materiel necessary to surge and sustain U.S. forces in times of conflict.

Finally, dual-use may be key to encouraging the retention of domestic production, research, and development activities of multi-national enterprises. This is accomplishable through a variety of means beyond buy-U.S. requirements, including the establishment of dual-use centers of excellence to attract and concentrate talent geographically, and requirements to provide local content for U.S. weapons and systems with foreign-developed technologies and capabilities.

2. Rationales for Commercial Industry Pursuit of Dual-Use Technologies

CONCLUSION: Commercial industry is primarily driven by a rate of return motive, as is appropriate within a free market economic system. Dual-use represents an opportunity for commercial and defense firms to expand markets, to more easily appropriate emerging technologies, and to improve their global competitive position.

There is much confusion over the role of private enterprises in dual-use activities. In a free market system, firms are expected to pursue the maximization of returns for their stockholders and owners, whether this be through profit maximization, market share maximization, or optimization of some other objective function. To the extent that dual-use fits with such goals it will be seen as attractive to firms, commercial or defense. Appeals to patriotism notwithstanding, this means that any dual-use program should seek to harmonize its goals and the way it does business with commercial market realities.

3. Possible Processes for Choosing Dual-Use Technology Investment Areas

CONCLUSION: The available processes for choosing technology investment focus areas devolve from well understood and documented approaches for technology decision making within the commercial and defense sectors. Advantages and disadvantages of the various approaches must be gauged against objectives pursued and should not be selected based upon abstractions or generalizations that do not fit the particular programmatic goals to be served.

Methodologies for choosing technology investments abound, with one survey of the literature containing references to over 200 separate articles and approaches; *The Economics of Commercial-Military Integration and Dual-Use Technology Investments* offers 9 points to be considered when choosing technology investments; selection criteria are also contained in *Beyond Spin-off, The Government Role in Civilian Technology*, and the *National Flat Panel Display Initiative*. The fundamental issue to be resolved is not the lack of choice methodologies, but the need to select one, or a combination, that fits the operational needs and goals of a dual-use program. The following considerations are important in making such a choice:

- What are the military and national security objectives of the investment?
- If economic or cost-effectiveness criteria are important, what are they?
- Who are the possible or likely winners and losers?
- To what extent are the benefits "public goods?"
- Will cost sharing be involved in the program, and will it be variable?
- Are domestic benefits a primary goal?
- To what extent will industry be involved in setting investment priorities?
- Will external sources of expertise be employed to judge the suitability of investments?

- How will similar or competing government programs elsewhere be handled?
- What are the political ramifications of the methodology selected?

4. Optimal Strategies for Integrating the Services into a Single Dual-Use Program Conducted at the OSD Level

CONCLUSION: In all cases examined, the optimal strategy for integrating the four military services into a single OSD-led dual-use program involves the creation of a joint program office. Operational strategies for such a dual-use program should be tailored to the particular goals of the program.

This paper began with a discussion of organizational parochialisms that have led to significantly different approaches to implementing dual-use. Using these and other guidelines we constructed four programmatic models: purposeful spin-off, direct spin-on, indirect spin-on, and industrial base strengthening. Throughout the paper we have continuously referred to these models during discussions of U.S. and foreign historical examples of government-involved dual-use efforts. In many cases, particularly those overseas, we found that a combination of dual-use results was possible through activities whose objectives went beyond military end goals.

To overcome parochialisms among the military services, their laboratories, and the civilian DoD leadership, a single, joint dual-use program is recommended. This is the favored vehicle for overcoming institutional and organizational barriers for other purposes within the Department, such as the need to develop weapons and systems suitable for missions across more than one service or agency. Operationally, such a program must be given the authority to define technology investment activities, as well as the responsibility for carrying out, monitoring, and advancing the fruits of dual-use activities within the Department. Given the broad charter attached to dual-use, optimally such a program would report directly to the highest possible levels within the acquisition community so that it would be employed on a strategic rather than a tactical basis.

Appendix A

RECOMMENDATIONS TO FURTHER COMMERCIAL-MILITARY INTEGRATION

Appendix A
RECOMMENDATIONS TO FURTHER COMMERCIAL-MILITARY INTEGRATION

The following lists of recommendations, summarized in Chapter 7, are here quoted at length for the convenience of the reader.

Jacques Gansler (1987) "The Need—And Opportunity—For Greater Integration of Defence and Civil Technologies in the United States," in *The Relations Between Defence and Civil Technologies* (Boston, MA: Kluwer Academic Publishers), 154–155.

- Effective technology transfer occurs primarily through people working together.
- Maximum civilian sector advantage is gained from military funding of "infant industries" due to the creation of new physical and human resources.
- When it comes to establishing a programme for integration, "institutional structure" and "policy emphasis" are far more important than the specific types of technologies selected.
- It should be recognized that large defence prime contractors are not "defense" firms but are "large systems producers" and that it is their management expertise—with complex, state-of-the-art advanced mission systems—that offers the greatest advantage in the non-defence world.
- Many existing structures retard market mechanisms from operating. Thus, a shake-up is needed in existing structures, in order to achieve the necessary changes that will allow/encourage integration to successfully catch on. Specifically, for technology transfer to be achieved, either the recipient structure has to change to accept the new technology ("absorption") or the technology itself has to change to fit the recipient ("adaptation").
- It very much matters whether R&D investment is made in the "user" or the "supplier" plants. For a single application (e.g., defence), it probably makes more sense to fund the end user of the R&D (e.g., the defence prime contractor). If one is stressing dual-use of the R&D investment, it may make more sense to fund the suppliers (e.g., the parts manufacturers of the material manufacturers).

- If one accepts the concept of "induced innovation," then the objective for R&D has a distance influence on the evolution of technology. Thus, specifying dual-use for the research programme (vs. defence only) is very likely to influence both which technology gets emphasized and how the technology evolves (e.g., stressing maximum performance, or cost and performance).

- R&D for advanced military systems can be focused on either quality or quantity of the next-generation systems, where the later is driven by cost considerations. Obviously, R&D to increase the quality of weapon systems will be much closer to that required for the civilian sector to become much more competitive internationally.

- In the past, military R&D far too frequently has not recognized how dependent it is on a strong civilian technology for its foundations.

- A key role for the government, historically, has been that of the "first buyer" in attempting to stimulate new fields of technology, i.e., defence buys it first for the military and then later it is applied to civilian sectors. (Examples of this range from the parts level, e.g., semiconductors, through full systems, e.g., supercomputers.)

- Capital equipment, engineering innovation, production labor forces and skilled management are the principal existing assets that should be maximized in any integration efforts—yet it must equally be recognized that these may well be very difficult to convert.

- It is reasonable to expect that two years are required as "planning time" for all the work that must be done to blueprint the changeover after a product has been selected for integration.

- The absence of careful planning and reliance on "crash" operations lead to a high probability of failure.

- In looking for good commercial products for conversion of military operations, one area that may be attractive is those products associated with "import substitution." Besides its economic attraction, this also has political appeal.

- In many cases, industrial conversion may require significantly reconstituting the top management of a company—towards the new market and its demands, i.e., bringing in key people with civilian expertise.

- It must also be recognized that to be successful in the civilian world defence-oriented firms may very likely have to have significant reductions in their administrative and engineering staffs. (A move that many have argued would be a desirable shift for defence business itself.)

Jeff Bingaman et al. (1991) *Integrating Commercial and Military Technologies for National Security: An Agenda for Change* (Washington, D.C.: Center for Strategic and International Studies), xv–xvi.

- Accounting Requirements: "[B]roaden the exemption from cost and pricing data for all commercial products and products procured in competitive bidding. . . . (1) exemptions from unique accounting regulations for those corporate operations whose primary business is in the commercial marketplace and (2) upgrading training in market research and price analysis for all DOD contracting officers." p. xv.

- Specifications and Standards: "[C]reate internal incentives, directives, and measures of successful implementation in each buying command that will move away from defense-unique processes or product requirements." p. xv.

- Technical Data Rights: "[C]reate a better balance between industry's proprietary rights and DoD's data requirements." p. xvi.

- Unique Contract Requirements: "[E]xempt commercial products and/or commercial suppliers from government-unique commercial obligations that are inconsistent with the Uniform Commercial Code that governs the majority of transactions in the private sector." p. xvi.

- Federal Laboratory System: "[A]s . . . laboratories are reduced in size . . . they should also be shifted in their focus in a way consistent with the broad movement toward an integration model (wherever applicable)." p. xvi.

Harold Brown et al. (1994) *Critical Issues in Defense Conversion: A Report of the CSIS Executive Committee on Defense Conversion* (Washington, D.C.: Center for Strategic and International Studies), 2–10, 13.

- Industrial Base for Defense: "The Committee's basic recommendation is that DoD must stop thinking in terms of a defense industrial base (DIB) and start thinking in terms of an industrial base available for defense (IBD). The essence of the IBD concept is to leverage existing dual-use capabilities for defense while at the same time subsidizing those capabilities that do not exist or would otherwise disappear from the civilian sector." p. 2.

- One of the Committee's Six Objectives for Defense Conversion: "The expansion of the industrial base available to defense. In may areas there are commercial equivalents for the items that DoD buys that are as good as, if not better than, what the defense-unique market can provide. Commercial firms can be brought into the IBD only through pro-active efforts at procurement reform (eliminate government-unique terms and conditions in contracts), standardization reform (eliminate overly prescriptive specifications and standards), and acquisition reform (integrate R&D and system requirements generation with existing commercial capabilities). pp. 4–5.

- Issues to be Resolved: "Creating an incentive structure for industry that would encourage the creation and maintenance of a dual-use capability. Incentives relate to the availability of capital to support technology conversion, the demand for the products of dual-use manufacturing capabilities, and the kind of administrative and regulatory burdens placed on industries by the government." p. 10.

- Reach Out to Industry for Dual-Use Solutions: "[D]efense R&D planners must be more aggressive in reaching out for dual-use solutions through cooperation with industry. Joint government-industry research and development in critical defense technologies has two significant benefits. First, it engages both state-of-the-art industry R&D and engineering expertise bringing concurrency into the process. Second, it promotes more rapid diffusion of government sponsored R&D into the private sector, doing away with the old 'sequential' model of technology transfer (e.g., transfer to commercial uses upon maturity of the defense technology)." p. 13

U.S. Congress, Office of Technology Assessment (1994) *Assessing the Potential for Civil-Military Integration: Technologies, Processes, and Practices* (Washington, D.C.: U.S. Government Printing Office), 10–15.

- Amenability of Industrial Base to Integration: "[N]ot all technologies, industrial sectors, or industrial tiers are equally amenable to integration. Complex defense systems requiring high levels of systems integration may not lend themselves to CMI. . . . Surveys indicate that firms at . . . lower tiers, small or large, may be more likely to be integrated, and the products and processes involved may be more amenable to integration than those at the prime contractor level. Indeed, many firms at the lowest tiers may not even know they are serving defense needs." p. 10.

- Savings from CMI: "The implied estimated savings of 20 to 60 percent for some individual case studies and savings of factors of 10 in a few selected cases, do not translate into proportional savings across the entire DTIB. Potential savings are difficult to quantify. OTA's analysis indicates that savings may be lower than some advocates have claimed, and be more difficult and take longer to achieve than many anticipate. Still, even if the percentage increase of total potential savings from greater CMI is relatively small (2 to 3 percent of the baseline DTIB spending), overall savings would amount to several billion dollars per year." p. 11.

- Timing of Systems Savings from CMI: "Given the probable slowdown in new programs, any new system development will be unlikely to appear sooner than seven to 10 years after implementation." p. 13.
- Estimate of Savings, Overall: "OTA made its own estimates of savings, as well as considering estimates from other studies. Based on the available data, it appears that total potential cost savings from increasing CMI might range from a few percentage points to as high as 15 to 20 percent of baseline DTIB spending depending on the set of policies implemented. . . . Applying the estimates of savings resulting from annual efficiency improvements made by the Defense Science Board Task Force on Acquisition Reform to OTA's estimates of potential for integration derived from OTA's industry survey, gives an overall estimated cost savings in the range of 5 to 10 percent of estimated baseline spending." p. 14–15.
- Technology Benefits: "If CMI is successfully implemented, its most important contribution may not be savings, but instead the preservation of a capability to support future national security objectives, i.e., ensuring the existence of a viable DTIB in the face of significant defense spending reductions." p. 15.

U.S. Congress, Office of Technology Assessment (1993) *Defense Conversion: Redirecting R&D* (Washington, D.C.: U.S. Government Printing Office).

- Military Spending as de facto Technology/Industrial Policy: [M]ilitary spending has sometimes been described as America's de facto technology and industry policy. If so, it is a blunt instrument of policy; it is an unfocused and expensive way of advancing important commercial technologies." p. 4.
- CRADA Delays at DOE Labs: "In early 1993, it still took 6 to 8 months or more to nail down most individual CRADAs—starting with the submission of proposals, which itself may have taken many months to develop in talks between lab and industry researchers." p. 19.
- ARPA as Premier Dual-Use Agency: "ARPA is becoming, de facto, a dual-use technology agency with a wide range of responsibilities." However, it "is still a defense agency with the primary mission of meeting military needs. Despite the overlaps in technologies having both defense and commercial applications, the match is by not means complete, nor are priorities necessarily the same." p. 29.

U.S. Congress, Office of Technology Assessment (1992) *Building Future Security: Strategies for Restructuring the Defense Technology and Industrial Base* (Washington, D.C.: U.S. Government Printing Office), 8–11, 20.

- Relying More on Civil Sector for Defense Technology Needs: "Advanced technology remains critical to the Nation's military strength. But the narrow focus on battlefield performance during the cold war should give way to a broader approach that takes account of defense manufacturing and maintenance issues and economic security. . . . In the future, military innovation might be sustained with relatively less funding and reorganized to take advantage of scientific and technological advances in the U.S. civil sector and abroad." p. 8.

- Dual-Use Path Recommended by OTA: "For much of the military materiel required by the DoD, OTA's analysis suggests that for reasons of cost, total capacity, and potential for innovation, the path defined by choosing dual-use technologies, private ownership, and competitive acquisition is preferable to alternate paths." p. 9.

- What is a World Class Defense R&D Capability?: An advanced defense R&D capability includes world-class personnel (individuals and teams); cutting-edge research that guards against technological surprise; robust efforts in critical technologies; a balance between the near-term technology needs of each Service and the long-term U.S. defense needs; strong links to manufacturing so that proposed weapons systems are producible; and integration with civilian R&D, even in the absence of a national consensus on directed federal support for civil technology programs." p. 11.

- Need for DoD to Rely More on Civil Sector: "The DoD must make great efforts to exploit civilian technology. Yet without regulatory changes, current performers of military R&D will not have incentive to improve their links to civil R&D. Three areas deserve attention. First, current rules governing independent research and development (IR&D) impose barriers between military and civil R&D activities within companies. Second, current rules allowing the government full rights to corporate technical data developed with government funding discourage specialized subtier firms—a primary source of innovation in defense systems—from developing technologies for both civil and military use. Third, reducing funding will preclude the DoD from maintaining world leadership in all defense-relevant technologies, increasing the need for the United States to benefit from R&D efforts in other countries. Yet current import and export restrictions inhibit interchange between defense and nondefense sectors and prevent the DoD from drawing on technology developed abroad, even by U.S.-based multinationals. p. 11.

- Decision to Emphasize Dual-Use Technologies: "A decision to emphasize dual-use technologies or civil-military integration would require the DoD and the Services to increase reliance on commercial firms, provide incentives for using non-developmental items, and stress performance criteria over rigid military specifications. These policies would require greater initiative on the part of government contracting officers than is currently allowed, and therefore better trained government acquisition personnel." p. 20.

U.S. Congress, Office of Technology Assessment (1991) *Redesigning Defense: Planning the Transition to the Future U.S. Defense Industrial Base* (Washington, D.C.: U.S. Government Printing Office), 13.

- Mobilization: "Mobilization Plans for this large base might be driven as much by what technologies are commercially available as by the desire to maximize military performance. In the Department of Defense (DoD) is to make more effective use of the broader civilian base, it will require better data about the commercial availability of dual-use products so that it can identify the industrial sectors in which civilian and defense production can be integrated most effectively."
- Foreign Dual-Use: "A recent OTA assessment of international arms cooperation noted that foreign defense firms in Europe and Japan are structured to make much more use of their civilian capabilities. This structure has resulted, at least in part, from different approaches to acquisition and accountability."

Appendix B

CONSIDERATIONS FOR SELECTING TECHNOLOGY INVESTMENTS

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The following lists of recommendations, summarized in Chapter 7, are here quoted at length for the convenience of the reader.

John A. Alic et al. (1992) *Beyond Spinoff: Military and Commercial Technologies in a Changing World* (Boston, MA: Harvard Business School Press).

Sample Criteria for Pathbreaking Technology Investments, pp. 388–389

- What are the principal technical goals or milestones against which success is to be judged? If economic or cost-effectiveness criteria are important, what are they?
- If the technical goals of the project can be achieved, what are the potential benefits to society?
- Given the potential social or commercial benefits of the project, what alternative technical approaches could lead to the same or similar benefits, and how do they compare with the proposed approach in terms of technical risk and economic cost? Are any of these alternates sufficiently promising to be pursued in parallel with the suggested approach until sufficient information is accumulated to permit a plausible choice?
- What are the potential "show-stopper" technical questions that, if not resolved favorably, might make the goals of the project unattainable? To what extent should the level of commitment to the project—and the development of ancillary technologies that would eventually be needed—be held back pending favorable resolution of these key technical questions?
- What is the qualitative appraisal of the social benefits versus costs, assuming favorable technical outcomes?
- What is the sensitivity of the potential social benefit/cost ratio to unexpectedly favorable or unfavorable technical outcomes?

- Who are the possible or likely winners and losers if the technical goals are achieved and the results are implemented on a significant scale? Have all the potential stakeholders been properly identified, particularly those that might be affected by externalities or spillovers if the technology should be deployed on a large scale?
- Assuming favorable technical outcomes, to what extent can the benefits be captured by the private sector? To what extent are the benefits "public goods" (nonappropriable to the innovating organization), and hence eligible for federal sharing of the costs of implementation and deployment beyond the original development and proof-of-principle?
- Who should be involved in judging the feasibility and desirability of the proposed project: technical experts, business managers and market experts, potential users, public officials, consumers, environmental impact experts? Who should represent the possible stakeholders (including future generations)? At what stage should the various stakeholders become involved?
- Who should be involved in the decision regarding whether or when technical progress warrants transition to implementation or application? If the ultimate application has positive externalities or public-good aspects, how should costs be shared between public and private sectors over time?
- Assuming technical success, what kinds of political, legal or institutional, and infrastructural changes would be needed to encourage commercial implementation? To what extent can federal policies bring about these changes? If it is politically unlikely that these changes can be brought about, how should this affect the desirability of public funding of the precommercial phase of the project?
- What are the potential cost savings or synergistic benefits of undertaking the project on an international basis? How would international planning and funding be likely to affect the later competitive position of U.S. firms if the technical goals are realized?

Sample Criteria for Strategic Technology Investments, pp. 397–398.

- Can a persuasive case be made that the industry to be assisted is sufficiently critical to a wide and important enough segment of the economy (high-value-added production, a source of high-wage employment) or to national security? Would the competitive health of many other linked industries be jeopardized if the domestic base of the applicant industry were replaced by import dependence?

- Is accelerated development, acquisition, and workforce mastery of technology really the key to maintaining competitiveness? Or are factors such as industrial structure, government regulation, unfair trade practices of competitors, obsolete management strategies, or inadequate workforce training more important?
- Does the applicant industry appear to have an adequate strategic plan, with defined goals and milestones that would result in sustained competitiveness, taking into account the likely response of its foreign rivals, and assuming adequate U.S. government policy response with respect to any nontechnological factors identified in question 2?
- Will the combination of government interventions and industry actions be sufficient to enable the industry to become self-sustaining so that it can acquire the follow-on generations of technology without government assistance?
- Assuming that strategic technology is supported through an industry consortium or government-industry partnership (perhaps involving universities or federal laboratories), will the parallel investments in the member companies suffice to ensure timely commercialization and meet the criterion of self-sustainability in question 4?
- What are the estimated benefits and penalties of including affiliates of foreign-based multinationals as members of the consortium or partnership eligible for U.S. government assistance? What, if any, criteria in the way of codes of conduct, structural characteristics, reciprocal national treatment by home government of foreign affiliates, and so forth, should be set for membership in consortia seeking U.S. government support?
- What is the necessary composition of a group for study and evaluation that will provide public credibility, industry confidence, and political legitimacy for a proposed investment in strategic technology? Are there industries, interest groups, or other stakeholders that are likely to be adversely affected by government support of a proposed project? How should these interests be represented in the decision process?
- How, by whom, and how frequently should progress toward meeting the goals of a strategic technology investment be assessed? What relative weight should be given to the assisted industry, independent experts, government officials, and Congress in assessing progress?

National Research Council (1992) The Government Role in Civilian Technology (Washington, D.C.: National Academies Press), 115–121.

- "The congressional request for this report included the mandate to recommend methods to strengthen government-industry cooperation in civilian technology. In particular, the law directed the academies to examine ways in which R&D cooperation might be structured to enhance the technological performance of U.S. industry. The following guidelines present an important framework for Congress and the executive branch as they design future cooperative ventures between government an industry and modify existing programs." p. 115.
- Principle 1, Cost Sharing: "A primary goal of any federal program that provides financial assistance to private firms should be to ensure that public funds are used to leverage corporate strengths in technology. The government should not attempt to override private market signals on the direction of development of promising technologies. Direct and unmatched government subsidies or grants to private firms for R&D or technology development projects can redirect scarce resources, both financial and human, into unproductive channels. To ensure the market relevance of R&D funded by the government in cooperative ventures, participating private sector firms or institutions (except nonprofit organizations) should bear a significant share of program costs. In most cases, this would involve private firms covering on the order of 50 percent of the total program costs of any pre-commercial R&D or technology project." p. 116.
- Principle 2, Industry Involvement in Project Initiation and Design: "The long-term objective of extending the government's financial commitment to pre-commercial R&D is to enhance U.S. productivity and raise its standard of living. To do this, support for R&D should be closely linked to commercial markets, as well as being in areas with the potential for wide industrial application. Projects to stimulate collaborative R&D ventures funded through government-industry partnerships should be proposed and structured by industry." p. 117.
- Principle 3, Insulation from Political Concerns: "The choice of R&D projects under an expanded federal program to support pre-commercial ventures should be based on technical and economic assessments of the merits of a specific R&D program. Evaluations of competing R&D proposals—either by a single firm or by groups of firms in a collaborative venture—that might be sponsored under an expanded federal program should be conducted by independent experts in the relevant scientific, technological, and economic areas. Political considerations should not influence R&D

programs' technical output, the location of R&D facilities, or the management of R&D projects." p. 118.

- Principle 4, Diversification of Investments: "Projects funded under an expanded federal program should complement and not compete or interfere with pre-commercial R&D and technology development activities under way elsewhere in the federal government. . . . . Diversification across projects by technology area is also essential to the success of an expanded federal program. pp. 118-119.

- Principle 5, Projects Open to Foreign Firms Characterized by Substantial Contribution to U.S. Gross Domestic Product: "Collaborative projects in pre-commercial R&D supported by the government under an expanded federal program should be open to foreign firms that contribute in a substantial manner to the U.S. gross domestic product (GDP). . . . In an interconnected global economy where goods and services flow rapidly across national boundaries, the U.S. government should seek to ensure that technology and production capability of the most up-to-date and competitive kind flows to U.S.-based development manufacturing facilities. There are significant benefits that accrue to the U.S. economy through the training, education, and skill enhancement offered by foreign-based corporations with U.S. affiliates." p. 120.

- Principle 6, Program Evaluation: "Rigorous technical and economic evaluation is an essential part of any technology program, especially of efforts to extend federal support for pre-commercial R&D. . . . The review proposed for an extended federal program in pre-commercial R&D should be conducted by an independent panel of experts, nominated by the President and confirmed by the Senate." p. 121.

U.S. Department of Defense (1994) *National Flat Panel Display Initiative* (Washington, D.C.: U.S. Government Printing Office), 2–3.

- DoD Dual-Use Strategy: "Any initiative under the dual use strategy, rather than maintaining defense-unique producers, seeks to foster the creation of a viable domestic industry that is competitive in global markets and able to meet defense requirements drawing on the commercial technology base. This dual use strategy may call for initial investments, but these investments will mean substantially lower future outlays as DoD acquires its products at much lower cost from commercial suppliers, and relies on a healthy, dynamic, domestic commercial industry to carry the weight of future R&D investments at the leading edge.

To be successful, new initiatives must be guided by six overriding principles:

1. The initiative must be of sufficient scope and duration to attract significant industry participation.
2. Industry must be willing to share in the costs of the initiative. The extent of industry willingness to undertake such costs is one of the most important measures of the initiative's value.
3. The Initiative should be based on principles of competition among firms and technologies. Central to this principle is the notion that the initiative will go forward only if industry responds with acceptable proposals and plays a lead role in determining the technologies to pursue.
4. Given the international nature of modern, high-technology industries and the emphasis on achieving leading-edge capabilities, DoD programs should have the flexibility to consider participation by foreign-owned entities that satisfies program objectives.
5. The initiative should be consistent with other government policy objectives. In particular, given the leading role of the United States in supporting an open international trading system and the benefits that such a system has for our economic security, the initiative should be consistent with U.S. obligations under the General Agreement on Tariffs and Trade and the World Trade Organization.
6. The initiative must be subject to sunset provisions and include clear measures of success to force and guide decisions about the continuing necessity of the initiative over the medium to long term."

Richard White and An-Jen Tai (June 1995) *The Economics of Commercial-Military Integration and Dual-Use Technology Investments*, IDA Paper P-2995 (Alexandria, Va.: Institute for Defense Analyses).

Recommendation: There is a difference between dual-use technology investments and investments that will ultimately lead to commercial-military integration. Any successful long-term CMI strategy must seek to differentiate between what is potentially dual-use from a technological standpoint, and what is both commercially viable and militarily useful from both a technological and private marketplace standpoint. The following nine criteria are recommended as guidelines for choosing dual-use technology investments.

- General Defense Relevance: Dual-use technology investments must have a clear connection to future needs and requirements of the Department of Defense. *General defense relevance* pertains to the requirement that all CMI projects must further the cause of national security, either directly for military purposes, or indirectly through industrial base improvements which may be demonstrated as integral to providing for the national defense. There are limits to the applicability of dual-use for DoD missions. This point cannot be overstated—it is not the purpose of DoD to fund projects which cannot be demonstrated as linked to national defense missions—regardless of their potential economic benefits.

- Attention to DoD Cost Drivers: Dual-use technology investments should target investments that promise to leverage significant cost savings for DoD. This *cost-reduction, rate-of-return criterion* is a corollary to so-called private rate of return. It focuses investments on the need to produce significant cost savings for national defense and emphasizes not only dual-use and co-production activities, but also personnel and training cost reductions. Approximately 50 percent of DoD's budget is in manpower. Derivative investments would result from an examination of the cost structure of current and future DoD weapons systems and the costs of those components which could be most affected by the introduction of new technologies. Attention to DoD cost drivers would also benefit commercial applications of technologies since cost is a primary commercial consideration.
- Commercial Market Drivers: A *commercial market driver* exists when a commercial demand for a product or process coincides closely with a defense need. Dual-use technology investments should demonstrate strong linkages to future commercial markets, both in terms of the potential size of these markets and the nationality of firms likely to be major players in the markets. There should be strong economic justification. In particular, CMI will require that firms clearly see a commercial return on their investments if an integrated industrial base is to become a reality. Without strong *a priori* commercial interest the lure of non-dual use investments will lead the private sector to emphasize other opportunities. In particular, maximum flexibility must be maintained when defining military requirements.
- Significant Technology Leveraging: To achieve desired defense-relevant goals, DoD should seek to *leverage the impact* of its dual-use technology investments by targeting areas in which there is clear under-investment by either the private sector, the public sector, or both. Expending DoD funds in areas where there are already large technology investments will have little leverage or pay-off. Therefore, investments should be made in domains where private sector interest is lacking because risk/reward ratios are too high or public sector investment has yet to be directed in earnest.
- Critical Path Roadblocks: Dual-use investments should target specific technical challenges that are unlikely to be addressed by the private sector alone. Such challenges constitute a *critical path roadblock* because

promising future technology developments are curtailed by the high cost of overcoming one or more technical challenges. In some cases such challenges will need to be targeted based on defense needs alone. However, we also demonstrated that what may begin as a military-unique investment may ultimately promote commercial markets by overcoming technical challenges where the private rate of return is low and results from technology investments are easily appropriated. Where appropriability or high social rate of return is an issue—essentially the creation of a public good—government investment or intervention is generally warranted.

- Full Spectrum Industry Participation: Maximum impact from dual-use technology investments is most likely to vary directly with the number of participants in a development project. By *full spectrum* we mean the need to involve all parties with an interest in a project in a partnership or research alliance. This is important for two reasons: It is necessary to make sure that the industry leaders are involved to improve the chances for success. And full spectrum participation precludes giving one firm an advantage over another (maintains "safe" distance from commercialization/ productization). The use of R&D alliances as a means to diversify investment risk was briefly touched upon in this paper.
- Portfolio and Cost Share/Capital Availability: A *portfolio* of dual-use investment projects with varying degrees of riskiness should be developed, and government support differentiated according to risk. There is a need to balance private rate of return with diversification of risk in a portfolio. Where risk is low, private sector investors should carry the primary burden for funding a project with commercial potential and military utility. Where risks are high and capital availability is an issue, there is a need to determine whether these circumstances derive from appropriability concerns or lack of information about opportunities. The level of support from the government and the quality of contributions from the private sector should then be adjusted according to the goals, anticipated returns, and risks of the planned investment.
- Process Technology Focus: *Process technologies* are key to industrial base integration and should be a focus of dual-use investments. The essence of an integrated commercial-military industrial base is the ability to co-produce commercial and military items. But because international competition is leading to global out-sourcing, maintenance of a world-class industrial base necessitates that domestically based U.S. firms maintain a competitive edge both in product and in process technology. To ensure that CMI is achieved and does not leave the U.S. "hostage" to foreign suppliers, DoD must promote cost-efficient process technologies that afford it and the commercial world distinct advantages over existing approaches to production. *All* dual-

use technology investments should therefore stress the importance of process technology development.

- Social Rate of Return and Pervasive Impact: Dual-use technology investments should seek to maximize social benefits, particularly as a result of external effects from projects as discussed in Chapter VI. A measurable, beneficial, direct impact on U.S. firms and national security should result from ultimate maturity of the technology development to be pursued. Beneficial impacts on firms include the creation of jobs, improvement in productivity, and increased profitability. Beneficial impacts on national security include reductions in weapon system costs, technological "leap-frogging" of foreign competitors' capabilities, and demonstration of co-production of military and commercial products. Indirect beneficial effects should also accrue to U.S. firms both upstream and downstream from products or processes expected to result from the technology development efforts.

Appendix C

10 USC SECTION 2501 FROM 1993 DEFENSE AUTHORIZATION ACT

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2501. Congressional defense policy concerning national technology and industrial base, reinvestment, and conversion

(a) **Defense Policy Objectives for National Technology and Industrial Base.**—It is the policy of Congress that the national technology and industrial base be capable of meeting the following national security objectives:

(1) Supplying and equipping the force structure of the armed forces that is necessary to achieve—

(A) the objectives set forth in the national security strategy report submitted to Congress by the President pursuant to section 104 of the National Security Act of 1947 (50 U.S.C. 404a);

(B) the policy guidance of the Secretary of Defense provided pursuant to [10 U.S.C. § 113(g)]; and

(C) the future-years defense program submitted to Congress by the Secretary of Defense pursuant to [10 U.S.C. § 221].

(2) Sustaining production, maintenance, repair, and logistics for military operations of various durations and intensity.

(3) Maintaining advanced research and development activities to provide the armed forces with systems capable of ensuring technological superiority over potential adversaries

(4) Reconstituting within a reasonable period the capability to develop and produce supplies and equipment, including technologically advanced systems, in sufficient quantities to prepare fully for a war, national emergency or mobilization of the armed forces before the commencement of that war, national emergency, or mobilization.

(b) **Policy Objectives Relating to Defense Reinvestment, Diversification, and Conversion.**—It is the policy of Congress that, during a period of reduction in defense expenditures, the United States further the national security objectives set forth in subsection (a) through programs of reinvestment, diversification, and conversion of defense resources that—

(1) promote economic growth in high-wage, high-technology industries and preserve the industrial and technical skill base;

(2) promote economic growth through further reduction of the Federal budget deficit and thereby free up capital for private investment and job creation in the civilian sector;

(3) bolster the national technology base, including support and exploitation of critical technologies with both military and civilian application;

(4) support retraining of separated military, defense civilian, and defense industrial personnel for jobs in activities important to national economic growth and security;

(5) assist those activities being undertaken at the State and local levels to support defense economic reinvestment, conversion, adjustment, and diversification activities; and

(6) assist small businesses adversely affected by reductions in defense expenditures.

(c) **Civil-Military Integration Policy**—It is the policy of Congress that the United States attain the national technology and industrial base objectives set forth in subsection (a) through acquisition policy reforms that have the following objectives:

(1) Relying, to the maximum extent practicable, upon the commercial national technology and industrial base that is required to meet the national technology and industrial base that is required to meet the national security needs of the United States.

(2) Reducing the reliance of the Department of Defense on technology and industrial base sectors that are economically dependent on Department of Defense business.

(3) Reducing Federal Government barriers to the use of commercial products, processes, and standards.

Appendix D

THE DEFENSE ADVANCED RESEARCH PROJECTS AGENCY

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The Defense Advanced Research Projects Agency (DARPA) is generally cited as the U.S. government agency with the greatest experience in supporting technology developments aimed at national security objectives as well as offering considerable technological spin-off to the civilian sector. Originally ARPA, in 1972 the organization's name was changed to DARPA to reflect political concerns that the agency retain strong defense relevance. To confuse matters, in 1993 the organization's name was changed back to ARPA as part of the Clinton administration's efforts to reinvigorate U.S. commercial competitiveness through technology investments and based upon Defense Authorization language indicating that this was also the "sense of Congress." And with the signing of the FY96 Authorization Bill, the name reverted once again to Defense Advanced Research Projects Agency. For simplicity, we consistently use DARPA here. This appendix, which is intended to offer a brief retrospective on the role of DARPA in promoting dual-use prior to the TRP, draws heavily upon a more complete history of DARPA projects, *DARPA Technical Accomplishments: An Historical Review of Selected DARPA Projects.*

A. THE ORIGINS OF DARPA

The immediate post-W.W.II era built upon advances in technologies that were fostered by the huge infusion of research from World War II. Nuclear weapons and propulsion, ballistic missiles, turbine engines, radar, sonar, and electronic computers all originated from defense needs and intensive R&D activities. Moreover, the U.S. and the U.S.S.R. both benefited from expatriate German and Japanese scientists and technologists, and the reservoir of technological developments that these countries had fostered during the war.

Immediately after the war the United States placed its priorities in the demobilization and revitalization of the domestic civilian economy concurrently with efforts to rebuild the devastated economies in Europe and Asia. The political confidence with which the U.S. entered the post-W.W.II era was soon to be shaken, however, by the capacity of the U.S.S.R. to field rapid advances in military technology. These advances made the Soviet Union a threat to the continental United States in ways never before experienced; the Soviets' detonation of a nuclear device in 1949 and a thermonuclear device in 1952 came as successive shocks which began to awaken the U.S. to the new challenges ahead.

On 4 October 1957, the Soviets launched Sputnik, raising the specter of the U.S.S.R. as an immediate technological threat to the United States. This "surprise" demonstrated how little attention the U.S. was paying to Soviet technological capabilities and priorities in space and missiles, and their implications for national security. It raised the issue of scientific and technological expertise at high levels in DoD, providing the impetus for the creation of both the Advanced Projects Research Agency and the position of Director, Defense Research and Engineering. These decisions were to have substantial impact on the evolution of technology policy and programs within DoD.

B. DARPA—A FOCAL POINT FOR ADVANCED TECHNOLOGY

DARPA was created as a direct response to the Sputnik challenge.[1] Its first years were focused on developing an integrated space program and with coming to grips with a highly contentious ballistic missile defense (BMD) program. These areas had similar characteristics—they stemmed from demonstrated Soviet advances that put U.S. technological prowess and R&D management into question; they were heavily charged with inter-Service rivalry; they were in response to a wide range of views held by the scientific and technical community on work that was needed; and, they entailed very large "technology risk/technology leverage" programs.

The convictions of President Eisenhower somewhat complicated the pursuit of space exploration by the United States(he believed that space should not be dominated by the military. This led to the creation of NASA in 1958, and the transfer to it by 1960 of all non-military space programs. Most military space programs became the domain of the Armed Services.

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1 DARPA fit into a Defense R&D structure that already was a complex nexus of Service R&D programs at laboratories; other research institutions, such as Draper Labs; the array of Federally Funded Research and Development Centers; and the National Laboratories that emerged from the nuclear weapons mission of the AEC labs—Lawrence Livermore, Los Almos, and Sandia. DARPA itself determined not to develop its own laboratories and relied on these other organizations heavily to be implementation agents for its research projects.

Subsequent to this transfer of authority, DARPA refocused its efforts on BMD through Project DEFENDER, which at one time represented approximately 80 percent of the agency's budget. DEFENDER was in fact a diverse set of programs that spanned basic phenomenology (atmospherics, physics of plumes, etc.), new missile concepts (e.g., the HIBEX fast burn booster), major advances in surveillance and detection technologies (phased array and over-the-horizon radar, infrared sensing), and new weapons technologies (high energy lasers, penetration aids). While the program came to an end in 1967, several of the research activities it spawned (such as advanced radar and infrared sensing) continued to evolve throughout DARPA's history.

Another major thrust that began at DARPA's outset was the VELA nuclear test detection program. This program involved a broad range of research that included space-based nuclear detection from satellite and seismic detection of underground detonations. In fact VELA is credited with supporting many important advances in seismic research and technology.

Both DEFENDER and VELA were hallmarks of subsequent DARPA programs. While based on military needs, the scope of these programs encompassed research into fundamentals and provided scientific and technological underpinnings that extended well beyond the immediate military applications, in some cases establishing major new scientific capabilities or R&D thrusts.

The early years at DARPA also saw the beginning of programs in broader, more generic research oriented toward long-term, enduring, open-ended technology areas with high potentials for transforming capabilities across a broad range of applications. Two early "assignments"(materials and information processing(have been sustained for over 30 years. They differed from DEFENDER and VELA in their heavy academic orientation and lack of explicit military requirements. From this perspective they would be categorized as "technology push" (as opposed to "requirements pull") and focused considerably more on research, particularly at the outset, than development. It is important to note also that both fields were recognized not only for their vast commercial potential but also for their importance as building blocks for defense capabilities. Because they were not military capabilities in themselves, the existing Defense R&D establishments tended to underinvest in them. Rather, these were enduring areas of technology development—DARPA in essence championed them as research fields. For instance, materials and information processing are both generic but at the same time applied fields that integrate across traditional disciplinary boundaries. In fact, DARPA played a major role in legitimizing academic research in these areas.

Therefore, DARPA provided a unique environment in which evolutionary and breakthrough technologies with long time horizons could be pursued without the narrow demands of explicit program applications. For many cases the strategy was indirect since it was found that the most effective course was to support broadly defined academic research and development leading to commercial exploitation to provide a basis for military adaptation and use. As a result, DARPA-sponsored research and development had substantial impact in the non-military environment, affecting both academic and commercial work.

C. DARPA TECHNOLOGY SEARCH MODEL

After its first decade, DARPA entered into a period during in which it transferred to application the major space and BMD programs to which it gave birth. Nuclear test detection, another priority activity, was reduced to a third of its original funding level. Project AGILE, which supported counterinsurgency during the Vietnam conflict, came to an end in the mid-1960s. Such transfers and redirected emphasis saw the budget for the organization reduced substantially as DARPA entered a period of redefining its goals and reasons for existence.

One characteristic of this period was an endeavor to identify new potential breakthrough technologies to avoid "technological surprise." A prime example of this was exploration of directed energy systems. Another example was emphasis on the transition of technology to military application with a management focus on more direct linkages to Service concerns. Reaffirming its significant importance, much of the DARPA program in the generic, infrastructure areas persisted throughout this period.

DARPA has focused on how to propel academic developments, such as those in artificial intelligence, and how to transfer these into application demonstrations. This effort to push technology out of the lab at times created tensions with the academic world. In retrospect, the second period in the agency's history may be seen as one of both contradiction and tribulation. It was a time of searching to define new relationships with technology producers and potential consumers, as well as a quest to discover where technology might have a major impact on future U.S. defense capabilities.

D. DARPA SINCE 1970

In 1975, Dr. George Heilmeier took charge of DARPA and led the agency to undertake a set of highly focused and ambitious technology thrusts. This transformation entailed redefining the types of programs that would be pursued, the manner in which they would be conducted, and the mix between application and basic research. These developments were supported by decisions made in the mid-1970s by the DDR&E, Dr. Malcolm Currie, and the Secretary of Defense, Dr. James Schlesinger, to emphasize advanced R&D as the basis for responding to the achievement of strategic parity by the U.S.S.R., as well as the numerical superiority of weapons fielded by the Warsaw Pact in the European theater. In particular, Currie looked towards DARPA to play a major role in technological initiatives to counter these threats.

To address its new role in providing break-through options for the military, DARPA laid out a set of technological thrusts over a 10-year horizon: follow-on forces attack with stand-off weapons, tactical armor and anti-armor programs, infrared sensing for spaced-based surveillance, high-energy laser technology for space-based missile defense, antisubmarine warfare, advanced cruise missiles, advanced aircraft, defense applications of advanced computing, and STEALTH. Importantly, many of these thrusts not only built upon, but substantially accelerated and coordinated, work already under way at DARPA.

To meet the requirements of the new thrusts, DARPA's funding expanded substantially during the next decade and a half, from $235 million in 1977, to $455 million in 1980, and finally reaching $1,451 million in 1991. Much of this increase was directed at large-scale system demonstration projects that were the focus of the research thrusts. Indeed the size of these thrusts led the next Director, Dr. Robert Fossum, to express concerns about their potential to overwhelm DARPA's ongoing technology base programs. Fossum also took a keen interest in the information processing and electronics area, and supported the VLSI program to reinvigorate academic research into microelectronics as a basis for fundamental advances in computer processing.

By 1981, when Dr. Robert Cooper became the director of DARPA, the technology thrusts had been in existence for over 5 years, and it was time to take stock of their accomplishments. Certain of the programs—ASSAULT BREAKER and STEALTH in particular—were seen as ripe for exploitation. With heavy OSD involvement, DARPA worked to transfer these to the Services. Other programs, such as the Forward Swept Wing X-29, were not yet seen as yielding the step-level results necessary to warrant further investment. And others, in particular the TEAL RUBY infrared surveillance satellite, suffered major difficulties that required them to be redefined and refocused.

Some of these "false starts" and difficulties might be seen as wasteful, and in retrospect alternative courses of action might appear to have been warranted. However, such judgments would not take into consideration the critical features of these DARPA endeavors. These programs were high-risk, ambitious efforts to demonstrate capabilities that had never before been attempted. In some cases their scope exceeded the management capabilities of DARPA, the Services, and contractors. But, these extraordinary efforts were also pushing simultaneously against multiple technological barriers under ambitious time schedules, often in the face of a range of operational and organizational barriers.

DARPA was not then, and is not today, in the business of assured success. Rather, it has sought to develop or refine paradigms through high-risk and high-payoff revolutions in technology. It has focused on enduring and very difficult problems for which incremental R&D was seen as insufficient. Failure of one or more technology demonstrations was not itself reason for DARPA to abandon an area. Rather, in some cases, failure merely signaled a need to redirect and redouble efforts in refocused, reconceptualized programs.

E. STRATEGIC COMPUTING—A SAMPLE DARPA SUCCESS STORY

As an example of the DARPA approach to applying advanced information processing technologies, it is interesting to consider the Strategic Computing Program (SCP). This program was similar in some respects to earlier, ambitious information processing-related technology demonstration thrusts. In particular, the SCP explicitly revisited some of the initial thrust areas that involved new computer processing developments (such as ACAT for ASW) that were at best "partial successes," and sought to apply the most recent advances in information technology research under a new management approach. As such, the program provided added focus and substantially greater funding with the aim of bringing to fruition the advances in the "emerging" information technologies DARPA had supported over many years. Its chief purpose was to forge new relationships among academic researchers in advanced computing and industry to create larger applications-oriented teams to "scale-up" significant advances in information processing, such as massively parallel processing and image understanding algorithms, that DARPA had fostered.

DARPA's persistent championing of a full range of advanced information processing technologies included novel computer systems concepts and architectures, revolutionary applications concepts such as artificial intelligence and neural nets, and "enabling" technologies such as VLSI and symbolic processing. These have been channeled iteratively into successive sets of demonstration vehicles to push innovation into application. The motivation for such iterative efforts is to further develop technologies for vital computationally intensive functions, including ASW, automatic target recognition, surveillance, and reconnaissance. Thus, DARPA has increasingly undertaken the strategic integration role as parallel developments in architectures, hardware, software, and electronics built upon and fed one another.

F. THE DARPA LEGACY

Persistence with a premium on demonstrated abilities and applications is today a DARPA motif. The primary challenge confronting the agency during its history has been to achieve technical results that meet and outflank actual and perceived threats. Perhaps DARPA's greatest dilemma, as well as the greatest tribute to its success, is that it now faces an environment in which the threat that so motivated its creation in 1958, and the strategic thrusts in 1975, has collapsed. As a consequence, DARPA faces a substantially new situation as the challenges confronting DoD are less clearly defined. How to define DARPA's programs in this new environment clearly must be a key element of DoD's future technology strategy.

Today, because of its reputation for "delivering the goods" in technology innovation, DARPA has been tapped to achieve technological progress in other domains as well. SEMATECH and other aspects of manufacturing technology were directed to DARPA by the Office of the Secretary of Defense and the Congress, but many of the programs mandated in this domain are not typified as "defense advanced research." As in the past, DARPA can take on an agenda of research that extends either beyond that which corresponds to its advanced research charter into weapons development, or into areas only indirectly link to Defense.

When the United States has been involved in conflict, such as during the Vietnam War and, most recently, the Gulf War, DARPA has provided a quick-turnaround capability for fielding special technologies for use in combat. At other times, it has supported advanced research into a range of infrastructure technologies that are only indirectly associated with military applications. Generally speaking, at any given time the latter have been relatively modest portions of the overall program. The concern is that these ancillary, collateral research activities are now viewed as much more central thrusts for the future DARPA. In fact, some of the programs that have been directed toward it are neither directly defense nor advanced research. One possibility is that the proliferation of such programs within the agency runs the risk of excessively diluting its capabilities and compromising its abilities to carry out its primary charter.

Not all "competitiveness" problems in the military or civilian arenas are technology problems, and not all technology R&D problems are necessarily those for which DARPA and its "unique style" are best suited. Arguments have been put forward that the changing international environment provides a substantially reduced security threat, and that DARPA should therefore be focused on broader economic and technological competitiveness concerns. A counterargument has been that the perturbations in the former U.S.S.R. are so recent and their outcomes so uncertain, that prudence requires continued effort to develop effective defense technology. In any case, a focus on such enduring problems as ASW, precision strike, and global reconnaissance are relatively generic and not specifically driven by the Soviet threat. Given the demise of the U.S.S.R., these thrusts may be revamped in their particulars, but their overall motivations and goals are still justified.

Other programs, closer to applications that were motivated particularly by the Soviet tactical ground threat in the European theater, clearly have reduced priority. The tractability of this threat is now replaced by an uncertainty of where future threats to U.S. security will arise. This uncertainty places premiums on some of DARPA's more enduring programs—surveillance, information processing for command and control, training for rapid response—and it increases the importance of bringing technology to bear to achieve very rapid but effective responses to threat situations.

Given the changing world situation the question becomes, What is the appropriate role for DARPA in redirecting technology away from providing the "most advanced" technology to meet the threat and toward using technology to make effective defense less costly? Some conceivable changes at DARPA would be greater focus on issues of weapons systems costs and the related time it takes to design, develop, and produce weapons systems, as well as a greater emphasis on programs associated with manufacturing technology and the more generically oriented programs in information systems that could affect the industrial production infrastructure.

The problem for DoD, much like American commercial industry, is that its technology development system has been optimized for creating new product concepts and designs, as opposed to developing and perfecting better ways of producing them. The concepts of more efficient, "affordable" defense production and more competitive civilian production then are cut of the same cloth. One is prompted to ask: "Can DoD generally, or DARPA specifically, deal best with Defense production efficiency problems in concert with U.S. industry overall, and if so how should it approach its role as part of this broader concern?"

Appendix E

SELECTED REFERENCES

Appendix E
SELECTED BIBLIOGRAPHY

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13. ABSTRACT (Maximum 200 words)

This paper is a survey of various issues regarding the efficacy and applicability of dual-use concepts to promote greater national security, both military and economic. It responds to five questions posed to the study team regarding the history, recent experience, and possible future of dual-use strategies to support and further the missions of the Department of Defense: 1. What are the potential benefits from dual-use for the military? 2. What are the motivation and rationales for commercial industry to pursue dual-use technologies? 3. What are the possible processes for choosing technology investment focus areas for dual-use projects, and are there associated advantages and disadvantages for each approach? 4. What are optimal strategies for integrating the four military services (Army, Navy, Air Force, Marines) into a single dual-use program under the Office of the Secretary of Defense (OSD)? 5. What are optimal strategies for conducting an OSD-level dual-use program?

For the purposes of this paper we chose to consider these questions in two categories. Questions 1 and 2 clearly relate to the underlying bases for pursuing dual-use, including history, institutional motivations, and technical and political considerations; Questions 3, 4, and 5 are programmatic in nature.

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