The U.S. Defense Contribution to Commercial Technology

A Report to NEDO

George R. Heaton, Jr.
David W. Cheney
Christopher T. Hill
Patrick H. Windham

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PREFACE

The study underlying this report was commissioned by the Washington, D.C., office of Japan's New Energy and Industrial Technology Development Organization (NEDO).

The report's authors, working together as the firm of Technology Policy International (TPI), have undertaken the study as independent consultants, although it should be noted that each has other professional affiliations and activities (see "About the Authors"). The opinions expressed in this report do not necessarily reflect the views of NEDO or the institutions with which the authors are affiliated.

George R. Heaton, Jr.**
Boston, MA
GRHeaton@aol.com

David W. Cheney
Silver Spring, MD
dcheney99@verizon.net

Christopher T. Hill
Knoxville, TN
Chrishll@erols.com

Patrick Windham
Arlington, VA
PatWindham@aol.com

** Project Manager and Managing Principal, Technology Policy International

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ABOUT THE AUTHORS

George R. Heaton, Jr. is a member of the faculty at the Worcester Polytechnic Institute in Massachusetts and an independent consultant in science and technology policy, environmental policy and law. Trained as a lawyer, Mr. Heaton has been on the faculty of the Massachusetts Institute of Technology, and has worked widely for public and private technical and policy institutions in the U.S. and abroad. Maintaining extensive professional and personal relations in Japan, Mr. Heaton was a Visiting Professor at Saitama University in 1986-87 and the First Foreign Scholar of the Ministry of Health and Welfare in 1989-90.

David W. Cheney is a Senior Consultant and the former the Director of the Center for Science, Technology and Economic Development at SRI International, where his work focuses on planning and evaluating science, technology, and innovation programs and institutions, primarily in the United States and Middle East. He is also an adjunct professor at George Mason University. Before coming to SRI in 1998, he was a senior executive in the U.S. Department of Energy, serving as director of the Secretary of Energy Advisory Board and advisor to the Deputy Secretary on industrial partnerships and national laboratories. He previously was a senior associate with the Council on Competitiveness, and an analyst with the Congressional Research Service. He has also held positions with the Internet Policy Institute, the Optoelectronics Industry Development Association, the Competitiveness Policy Council, and the Institute for Policy Science at Saitama University in Japan. He has a PhD in public policy from George Mason University, a MS in Technology and Policy from MIT and a BS in Geology & Biology from Brown University.

Christopher T. Hill is Professor Emeritus of Public Policy and former Vice Provost for Research at George Mason University in Fairfax, Virginia. He is currently a Senior Fellow at SRI International. After earning three degrees in chemical engineering and practicing in that field at Uniroyal Corporation and Washington University in St. Louis, he has devoted the past four decades to practice, research and teaching in science and technology policy, including service at MIT, the Office of Technology Assessment, the Congressional Research Service, the National Academy of Engineering and the RAND Critical Technologies Institute.

Patrick H. Windham is a consultant and university lecturer on science and technology policy. From 1999 to 2012 was a Lecturer in the Public Policy Program at Stanford University. From 1984 until 1997 he served as a Senior

Professional Staff Member for the Subcommittee on Science, Technology, and Space of the Committee on Commerce, Science, and Transportation, United States Senate. He helped Senators oversee and draft legislation for several major civilian science and technology agencies and focused particularly on issues of science, technology, and U.S. industrial competitiveness. Mr. Windham received an A.B. from Stanford University and a Master of Public Policy degree from the University of California at Berkeley. He currently lives in Arlington, Virginia.

The U.S. Defense Contribution to Commercial Technology

1. Introduction

This paper provides a framework for understanding the influence of research and development (R&D) and the adoption of new technologies by the U.S. Department of Defense (DoD) and other federal agencies with a defense mission on the advancement of commercial technologies.

This is a very large topic, which this short paper cannot possibly cover comprehensively. Instead, we focus on a few key aspects of the influence of the U.S. defense system on commercial technology development. Thus, this paper is a preliminary exploration intended to stimulate discussion and help guide further investigation.

The paper begins with an overview of the contributions of the DoD system to commercial technology development. It then provides some background on the strategic and political context that helps explain why DoD has played such an important role in commercial technology development, including the importance of advanced technology to U.S. defense strategy, the sheer size of the defense system, and the nature of political support in the U.S. for Federal support of technology for defense versus commercial technology. It then turns to a very brief overview of the defense technology development system, emphasizing its size, complexity, and diversity. The paper closes by addressing some key questions about the role of DoD (and other defense-related agencies) in the development of commercial technology. These questions include:

- What type of commercial innovation does the U.S. defense system contribute to?

- Which elements of the U.S. defense system contribute the most to commercial technology?
- What aspects of DoD's technology development system make it effective?
- How has DoD's impact on commercial technology changed over time?
- What are weaknesses of the DoD technology development and adoption system?
- What lessons does the DoD experience suggest about how government can support commercial technology development?

2. Overview of the Contributions of DoD Technology Development to Commercial Technology

Over the last 70 or so years, the U.S. Department of Defense has contributed substantially to the development of many technologies that have had a large impact on commercial technology. Here are just a few examples:

- Jet aircraft. The Boeing 707, the first widely successful jet airliner, was based on a prototype that was developed to be the basis for a military tanker, the KC-135 military tanker.[1]
- Many key space technologies, including advanced rocketry and space satellites, were originally developed under defense funding (before many of DoD's activities were moved to NASA when it was established in 1958). (Other countries, of course, have also contributed to space technology.)
- Nuclear power was largely developed with military support. In the United States, support for nuclear power was shifted from the Department of Defense to the Atomic Energy Commission and later the Department of Energy, but nuclear power R&D has continued to be conducted for military purposes. Furthermore, the first civilian nuclear reactors benefited from the development of nuclear reactor technologies for U.S. Navy submarines.

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[1] http://www.boeing.com/boeing/history/boeing/707.page.

- Microwave ovens were developed by Raytheon Corporation as a direct spinoff from a defense-funded research project on improved radar .
- Defense was instrumental in the development of both computing and microelectronics. As is well known, the Internet developed from DoD projects. The computer mouse and many of the foundations of personal computers were developed with DoD support. DoD also supported the development of visualization methods and displays.[2]
- Optoelectronics benefitted heavily from DoD support, including the development of wave division multiplexing that greatly increased the capacity of optical fiber.[3]
- Artificial intelligence, such as speech recognition and robotics, has benefitted heavily from DoD support.
- Numerically controlled machine tools were developed at MIT and in the aircraft industry, largely through DoD support.[4]
- Computer aided design and engineering benefited significantly from DoD support.
- The global positioning system (GPS) was developed and implemented by DoD.[5]

It should be noted that DoD was not the only supporter of many of these technologies. In some case the original advances came through DoD supported work but many other organizations and companies contributed to subsequent advances. In other cases, the

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[2] Two excellent histories of the contributions of government R&D funding, particularly DoD funding, to computing, computing networking, and microelectronics are: Committee on Innovations in Computing and Communications: Lessons from History, National Research Council, *Funding a Revolution: Government Support for Computing Research*, Washington: National Academies Press, 1999; and Committee on Depicting Innovation in Information Technology, National Research Council, *Continuing Innovation in Information Technology*, Washington: National Academies Press, 2012.

[3] Optoelectronics Industry Development Association, *Creating Bandwidth for the Internet Age: How Research Investments, Innovative Companies, and the Financial Community Made America the World's Leader in Fiber-Optic Communications*, September 2001. (Disclosure: TPI Principals Patrick Windham and David Cheney were the main authors of this OIDA report.)

[4] See http://en.wikipedia.org/wiki/History_of_numerical_control.

[5] See http://en.wikipedia.org/wiki/Global_Positioning_System.

basic technology may have originated outside of DoD, but DoD saw the potential importance of the technology and invested heavily in its subsequent development.

Many of these examples are historical. However, defense funding and performance of R&D continue to contribute to important emerging technologies, such as autonomous vehicles and biomedical engineering,

In addition to these highly visible areas, where DoD funding has contributed to new breakthrough technologies, many more subtle advances have come in the form of support for specialized materials, lubricants, seals, ruggedized electronics and other technologies.

Also, by funding interdisciplinary teams to address new science and engineering challenges, DoD programs have helped create new technical disciplines and communities, including materials science and engineering, computer science, computer networking, artificial intelligence, and, more recently, engineering biology. The creation of new communities of professors, graduate students, and company researchers is one of DoD's most important contributions to U.S. technology development.

3. Strategic and Political Context

There are several reasons why defense plays a particularly important role in commercial technology development in the U.S.

U.S. defense strategy. The first is the importance of technological superiority to the overall defense strategy of the United States. At least since the Second World War and expanding since the launch of Sputnik in 1957, the U.S. has relied on technological superiority, if not technological dominance, for its defense. There are several reasons for this:

- The U.S. has assumed worldwide defense and security obligations that are large in relation to the U.S. population, and often the U.S. has faced potential adversaries that have larger numbers of troops and weapons. For example, during the Cold War the U.S. and its NATO allies faced Soviet forces with larger numbers of soldiers, tanks, and aircraft. Advanced technology was seen as the way to offset the Soviet Union's numerical advantages. Today, with a relatively small all-volunteer military, the U.S. relies even more heavily on advanced technology. [6]
- As an affluent democracy, the U.S. seeks to minimize U.S. casualties and minimize the number of its people put at risk in combat situations.

Consequently, the U.S. relies heavily on technological superiority to project force and wage wars while minimizing the risk to U.S. military personnel.

Large budgets. DoD also plays an important role in technology development simply because of its sheer size and the size of its budget. The U.S. Department of Defense budget for fiscal year 2015 is $496 billion, with an additional $64 billion for overseas operations. In addition to the Department of Defense, several other departments and agencies are strongly defense-related. These include the Department of Energy's National Nuclear Security Administration, which is responsible for nuclear weapons and has 2015 budget of $11 billion; the Department of Homeland Security (DHS), which has a budget of $38 billion; the Department of Veterans Affairs, with a budget of $65 billion; and various intelligence agencies.[7] Overall, the total national security-related budget is close to $700 billion, which is comparable in size to the GDP of nations like Argentina or Saudi Arabia.

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[6] During the past fifteen years, the emergence of powerful non-state adversaries has tested the validity of the U.S.'s technological dominance strategy, but such dominance continues to be a cornerstone of U.S. defense capabilities, even when the new kinds of adversaries operate with a very different model of warfare.

[7] Office of Management and Budget, *Budget of the United States, Fiscal Year 2016*. Summary Table. S-11. https://www.whitehouse.gov/sites/default/files/omb/budget/fy2016/assets/tables.pdf.

Two parts of the DoD budget play major roles in U.S. technology development and adoption. First, of course, DoD invests heavily in R&D (which it calls "research, development, test, and evaluation" – RDT&E). In U.S. federal fiscal year (FY) 2015 the DoD RDT&E budget is $64 billion, which is larger than the total funding for most militaries around the world. President Obama has requested nearly $70 billion for DoD RDT&E for FY 2016. DoD's R&D operations include both (a) investments in new science and technology and (b) the development of new weapon systems that use this new technology. While the investments in new science and technology have led to major innovations such as the Internet and advanced electronics, the systems development work is also important; it has helped refine new technologies such as advanced composites, advanced rockets, and unmanned aerial vehicles.

The second important part of the DoD budget from the point of view of technology development is the funding for procurement of weapons and equipment. Since the Second World War, DoD has often been the "first buyer" of new technologies. Since the military values technological superiority, DoD often will pay the high costs of new technology. Furthermore, in the pursuit of technological superiority DoD is sometimes willing to invest in risky new technologies that commercial companies may not be willing to consider. Sometimes this procurement has significantly helped new companies, including companies that primarily sell commercial products. A famous example is that Intel Corporation's first major sale of integrated circuits was to the U.S. Air Force. Sales to the government help companies make initial profits and learn how to make advanced products more efficiently and at lower cost, eventually helping position the companies to move into commercial markets.

Table 1 summarizes both FY 2015 spending for DoD and President Obama's request for FY 2016. As mentioned, the President has requested nearly $70 billion for RDT&E. The

President is requesting nearly $115 billion in FY 2016 for procurement, much of which would incorporate advanced technologies.

Table 1. DoD Total Budget[8]

$ in Thousands Base Budget	FY 2015 Enacted	FY 2016 Request	Delta FY16 - FY15
Military Personnel	139,993,999	139,939,434	-54,565
Operation and Maintenance	246,345,015	250,041,175	3,696,160
Procurement	101,273,354	114,992,064	13,718,710
RDT&E	63,822,806	69,976,397	6,153,591
Revolving and Management Funds	2,225,830	1,875,582	-350,248
Defense Bill	**553,661,004**	**576,824,652**	**23,163,648**
Military Construction	5,652,265	7,024,439	1,372,174
Family Housing	1,126,735	1,413,181	286,446
Military Construction Bill	**6,779,000**	**8,437,620**	**1,658,620**
Total	**560,440,004**	**585,262,272**	**24,822,268**

Note: Reflects Discretionary Budget Authority *Numbers may not add due to rounding*

U.S. political culture. A third reason for the importance of the defense in developing commercial technologies has to do the with the U.S. political culture. In keeping with a general opposition to a strong national government, many in the United States do not agree that supporting commercial technology development is an appropriate function of government. On the other hand, nearly everyone agrees that national defense is an important and essential function of government. As a result, political support for funding technology development is much stronger if it is done for defense rather than commercial purposes. Often, proponents of government support of a new technology may fail to get support for a commercially-oriented program, but may succeed in

[8] Office of the Under Secretary of Defense (Comptroller), Chief Financial Officer, *United States Department of Defense Fiscal Year 2016 Budget Request: Overview*, page A-5, http://comptroller.defense.gov/Portals/45/Documents/defbudget/fy2016/FY2016_Budget_Request_Overview_Book.pdf.

getting support for the same technology if it can be justified as important for national defense.[9]

Defense funding has helped develop many technologies that are recognized as being important for both defense and commercial purposes, such as semiconductors and computing. The large size of the defense enterprise means that the national security system has many of the same technology needs as the economy as a whole (although with different priorities). The defense enterprise not only needs advances in weapons, but also needs advances in computing, in materials, in communications, in manufacturing, in energy, in medicine and health care, in logistics, in educational technologies, and in many other areas. As a consequence, the national security agencies, while spending the majority of their RDT&E funding on weapon systems development, have also funded R&D across very broad areas of science and technology.

4. The Defense Technology Development System

This section provides a sense of the size, scope and complexity of the defense technology development system. As one would expect with a system that spends over $60 billion on R&D, the defense technology development system has many pieces, which are described in the following.

Policy direction for defense R&D comes from the Assistant Secretary of Defense for Research and Engineering – the ASD (R&E) – who reports to the Under Secretary of Defense for Acquisition, Technology and Logistics. In turn, the Under Secretary reports

[9] This phenomenon is not limited to technology development. For example, the massive U.S. investment in its national network of interstate highways was originally justified on the basis that it was needed to secure the defense of the nation by enabling rapid transportation of personnel and materiel across the country. Similarly, millions of U.S. students have received federal government loans to help them attend colleges and universities. The legislation that established the federal student loan program is called the National Defense Education Act.

to the Secretary of Defense.[10] Thus DoD R&D is overseen as an element of the larger system for acquiring new equipment for the military.

Most defense R&D is conducted through the laboratories and programs of the three individual armed services: the Army, the Navy (which includes the Marine Corps), and the Air Force. Each service has a separate R&D funding office, which provides funding to a range of institutions, including universities, companies and its service's laboratories.

For example, the Chief of Naval Research oversees the Office of Naval Research (ONR), which primarily funds research in academia and industry, as well as the Naval Research Laboratory (NRL) and several other Navy and Marine Corps laboratories. The Army has a similar structure, with the Army Research Office that funds research in universities and companies, the Army Research Laboratory, and a number of Army Research, Development, and Engineering Centers (RDECs). Similarly, the Air Force has the Air Force Office of Scientific Research and the Air Force Research Laboratory, as well as other smaller specialized laboratories.

Although the services' R&D systems have generally similar structures, their organizational details differ. For example, in the Navy the central research laboratory is organizationally under the research office (ONR), whereas in the Air Force, the research office is organizationally under the research laboratory. These details, which reflect their different histories, are not important for this paper, except to make the point that these organizations are complex and not uniform.

In addition to its own laboratory, each of the services also makes use of a variety of other research performers. These include University Affiliated Research Centers

[10] The ASD (R&E) directly oversees certain research programs, including some university research, and also helps to coordinate the R&D activities of the three military services. As discussed earlier, the services have their own R&D organizations.

(UARCs), which are research centers that are operated by universities and are devoted to military work, and Federally Funded Research and Development Centers (FFRDCs), which are research or analysis centers that are operated by contractors (which may or may not be universities). Some of these facilities are quite large. A prominent UARC is the Applied Physics Laboratory at Johns Hopkins University, which employs 5000 people, and works primarily for the Navy but also for other defense organizations.[11] A prominent FFRDC is MIT's Lincoln Laboratory, which employs 1700 and works primarily for the Air Force but also serves other military agencies.[12]

The Army, Navy, and Air Force research offices are also substantial supporters of university research and graduate education in fields of science and engineering that are important to them. This support takes the form of research grants to universities that support graduate research assistants as well as fellowships paid directly to graduate students.

One key defense R&D agency, the Defense Advanced Research Projects Agency (DARPA), is not under one of the services but rather part of the Office of the Secretary of Defense; it reports to the Under Secretary for Acquisition, Technology, and Logistics and works on projects that serve all of the services. DARPA (which will be discussed in more detail below) supports advanced technology development projects that are carried out by teams of researchers in companies, laboratories, and universities.[13]

Much of the defense RDT&E budget is actually spent supporting major defense contractors that develop and test new technologies, including very expensive new weapons systems. DoD contracts with such contractors allow them to use a small,

[11] http://en.wikipedia.org/wiki/Applied_Physics_Laboratory.
[12] http://en.wikipedia.org/wiki/MIT_Lincoln_Laboratory.
[13] A recent report from DARPA describes its mission, current priorities, and some of its contributions over the decades to both military and commercial technologies. Defense Advanced Research Projects Agency, *Breakthrough Technologies for National Security*, March 2015, http://go.usa.gov/3rut4.

negotiated portion of contract funds they receive to do independent research and development (IR&D) projects that enable the contractors to enhance their capabilities or explore new concepts that may be of interest to DoD in the future[14]

An important part of the defense technology development system is the military services that are the customers for new technologies. Representatives of the military services provide guidance to R&D funders and performers about their needs that might be met through new technology. They are listened to carefully because they provide much of the development funding and because the services must be willing to purchase the end products of R&D efforts if they are to make a difference.

Not all DoD technologies are developed based on the stated needs of the services, however. For example, DARPA developed some new technologies that the services were resistant to adopt, at least at first. Unmanned aerial vehicles (UAVs) are one example; the Air Force initially did not want them. In most cases, however, DARPA and the service R&D organizations try to work on technologies that they believe will have a customer in the services.

5. Key Questions about the Role of Defense Technology in Commercial Technology Development

Defense technology is clearly an important contributor to civilian technology development. But is its influence due primarily to its size, or are other aspects of the system important to technology development?

[14] The IR&D program can best be understood as a substitute in the government contracting world for funds that commercial companies might set aside from retained earnings in order to invest in future-oriented R&D. Because of the general provisions of government contracting regulations, defense contractors cannot charge enough to the government customer to support future-oriented R&D in the absence of the IR&D program.

This section of the paper addresses this overall question by commenting on the specific "key questions" posed in the Introduction. The answers to these questions help explain the strengths and weakness of the DOD system and help identify possible lessons regarding how best to develop defense technologies and commercial technologies.

5.1 What types of commercial innovation does the DoD system contribute to?

The Department of Defense contributes to commercial innovation, but it does not contribute equally to all kinds of commercial innovation.

Most of the innovations for which DOD is best known are science or technology-driven innovations that create completely new or significantly advanced capabilities, often leading to new companies and industries. Many of the best-known examples of DoD-supported innovations fall into this category:

- Computers, networking & artificial intelligence
- Robotic surgery
- Autonomous vehicles
- Global Positioning System (GPS)
- Micro-electro-mechanical Systems (MEMS)
- Microsatellites

Some of the best known significant DoD-supported advances are those where DoD not only supported the development of specific products or services but also the broader "technical infrastructure" for making or using those products or services. For example, it created the global positioning system (GPS), supported the development of advanced semiconductor manufacturing technologies and semiconductor industry "technology roadmaps," and funded the development of both computing networking equipment and protocols, leading to the Internet.

Manufacturing technology is one field where DoD's role is still significant but less important than it once was. In the past, DoD played a major role in advancing manufacturing, including 19th century projects to create interchangeable parts for rifles, mid-20th century work in automation and mass production, and more recently manufacturing for novel materials (such as high temperature metals and composites for aircraft) and for semiconductors (including support in the 1980s and 1990s for the SEMATECH consortium and advanced lithography). However, since the early 2000s DoD has provided relatively little support for new manufacturing technologies. Today, DoD plays a limited but important role in manufacturing such as R&D on manufacturing for emerging technologies, such as nanotechnology, and specialized niche areas, such as stealth weapons. In addition, the Obama Administration has used DoD as a source of funds for several of its new government-industry manufacturing institutes under the National Network for Manufacturing Innovation (NNMI) Program.[15]

DoD does not appear to be as relevant to many other commercially important types of innovation. For example, DoD has made little apparent contribution to business process innovation, such as Dell's made-to-order computers or Amazon.com's model for electronic commerce (although many such business process innovations depend on earlier DoD-funded advances in computing and networking). Similarly, DoD contributes little directly to the many innovations that use information technologies to provide new consumer benefits and commercialized by companies such as by Google,

[15] For information on the NNMI and its institutes, see: http://manufacturing.gov/nnmi.html. See also the section on manufacturing in "Science, Technology, and Innovation Policy Initiatives during the Second Obama Administration," report to NEDO by Technology Policy International, George R. Heaton, Jr., Christopher T. Hill, and Patrick H. Windham, May 2013

Facebook, Instagram, Uber, and many others. Even in these domains, however, DoD has made important contributions. For example, Apple's Siri App is a direct spin-off from DARPA-funded projects at SRI International.[16]

DoD is not known for contributions to design-based innovation, such as those for which Apple is famous, although DoD has contributed to human factors engineering, which relates to design.

DoD has played large roles in creating a number of radically new high performance technologies, but has contributed much less to development of less-expensive variations of these technologies that disrupt mass markets. For example, DoD supported much early work in digital computing, but did not support the development of personal computers. It supported many of the technologies used in smart phones, but not the packaging of those technologies into mass market products.

Also, DoD funding appears to contribute little to the flow of incremental innovations that are key to progress in technologies such as automobiles, commercial electronics, consumer products, or most of the other things produced and sold in the commercial market place. There are exceptions to this--as mentioned earlier, DoD has supported continuous improvements in semiconductor manufacturing technology, and defense contractors use DoD funds to pursue incremental innovation in weapons systems.[17]

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[16] See http://www.huffingtonpost.com/2013/01/22/siri-do-engine-apple-iphone_n_2499165.html.

[17] Unlike most commercial marketplaces, the need for interoperability, ease of repair in remote and difficult circumstances, and the need to train often-inexperienced technicians in their operation create incentives not to update technologies in the field, which can discourage incremental improvements in defense systems.

5.2 Which elements of the DoD technology development system contribute to commercial technology?

While all elements of the DoD R&D system generate new knowledge and technology that likely contributes to commercial technology, a high percentage of the most significant and best known DoD-supported innovations that have commercial impact appear to have resulted primarily from a small subset of the DoD R&D system – particularly DARPA projects that have led to both defense and commercial applications

Of the DoD RDT&E budget, only 17 percent is for the so-called "Science & Technology Program," a subset of DoD R&D that consists of basic research, applied research and advanced technology development. The other 83 percent is predominantly for development, testing and evaluation of weapons systems,[18] activities that are widely believed to have less direct impact on civilian technology than those in the Science and Technology Program

Different parts of the DoD system have been important in the development of different technologies:

- DoD has provided broad support for some fields of science and technology (e.g., computing, artificial intelligence, advanced materials) that enabled many commercial technologies. This support came from DARPA as well as from the Army, Navy, Air Force, and other DoD science offices.

- For many breakthrough innovations, DARPA's support of applied research and advanced technology development projects has been very important. DARPA projects have led to prototypes of many advanced technologies that later have been adapted to make commercial technologies. Some recent examples of this include advances in robotic surgery that led the commercial DaVinci system, voice recognition software that led to Nuance software, and projects for personal

[18] Office of Management and Budget,"Research and Development," in *Budget of the United States, Fiscal Year 2016. Analytical Perspectives*, https://www.whitehouse.gov/sites/default/files/omb/budget/fy2016/assets/ap_19_research.pdf.

assistants that led to Apple's Siri. DARPA's annual budget is about $2.8 billion, out of DOD's nearly $65 billion R&D budget.

- As noted earlier, in some cases DoD investment in infrastructure and procurement has also been important (e.g. semiconductor electronics, the Internet, and GPS), as are some investments in manufacturing technology.

- In addition to funding R&D projects, DoD has also been an important supporter of graduate education in science and engineering. In the U.S., graduate students in science and engineering are supported financially through fellowships and research grants from research agencies, rather than from the Department of Education. As an agency with extensive need for science, technology, engineering, and math (STEM) graduates, DoD also has an important responsibility to support graduate education in these fields, and many of students supported by DoD grants and contracts later contribute to commercial technology development throughout their careers.

- Spin-offs from DoD's systems development work carried out by defense contractors do not appear to be common in recent decades. However, some component and materials technologies migrate from defense companies to commercial firms; advanced composite materials are one example.

5.3 Which aspects of DoD's technology system make it effective?

There are several reasons why DoD has made many contributions to civilian technology development. One explanation is simply the size of its R&D budget: it is such a large R&D enterprise that it is likely to have some impact on technology. We believe, however, that the size of the RDT&E budget alone is not the main reason for DoD's contributions. Four other reasons can explain why DoD is so effective in developing breakthrough technologies that have both defense and commercial benefits.

First, DoD is oriented toward high performance rather than low cost. DoD tolerates high costs both in research and in the systems it buys and operates in order to obtain very high performance. With respect to research, DoD research projects funded at universities tend to provide more generous support than grants from the National Science Foundation or the National Institutes of Health, enabling bigger R&D projects and attracting top talent to work on the projects. The fact that DoD is willing to pay a premium for high performance technologies means that advanced technology development teams can target products that create new capabilities, almost regardless of their cost. Later, costs may come down after a product is initially developed for defense markets, and it may then be introduced into more cost-competitive commercial markets.

Second, DoD's ability to fund the entire innovation process is important. DoD typically supports all stages of a system's evolution, from basic research to procurement and implementation. DARPA and some other parts of the Department are especially effective at developing new technologies. But they do not exist in isolation; they are parts of much larger DoD and national innovation systems. They draw upon basic research and educated scientists and engineers. And later other parts of DoD, defense contractors, and, sometimes, commercial companies turn new prototype technologies into actual products and services.

The DoD system has some of the same characteristics that made AT&T and IBM such powerful technology developers in their heyday. Because those companies operated, for different reasons, as quasi-monopolies, they had the money and freedom to fund technology work from basic research to application. That is, like DoD, they had the freedom to fund technology in a non-competitive market that allowed them to charge premium prices for their products and services and to spend a portion of their high profits on R&D and innovation

Third, DoD's investments in new technologies are particularly important to U.S. commercial companies because (a) most commercial firms are not monopolies and have difficulty funding long-term, risky technology projects; and (b) as discussed earlier, the U.S. Government generally invests little money to directly help commercial firms develop new technologies.[19] DARPA and other DoD agencies are therefore the main American sources of government funding for the development of new, radical, breakthrough technologies.

Fourth, DARPA uses a particularly effective model of R&D management. The DARPA model involves setting aggressive but theoretically achievable technical goals, using talented program managers, building interdisciplinary teams of the very best available talent, and rigorously measuring progress through the use of project milestones.

5.4 How has DoD's impact on commercial technology changed over time?

DoD R&D as a percentage of overall R&D. While DoD remains an important funder of breakthrough technologies, today it is certainly a smaller player in overall U.S. and global R&D than it was in the 1950s and 1960s. Three facts show why.

First, today the U.S. federal government funds a smaller proportion of total U.S. R&D than it once did. In 1963, for example, the federal government funded 66 percent of all U.S. R&D.[20] And, substantially more than half of the large federal investment was spent for defense purposes. By 2011, however, business funded 63 percent of total U.S. R&D and the federal government funded only 30 percent.[21] And, a little more than half of the federal R&D was spent for defense purposes. Roughly speaking, therefore, the defense

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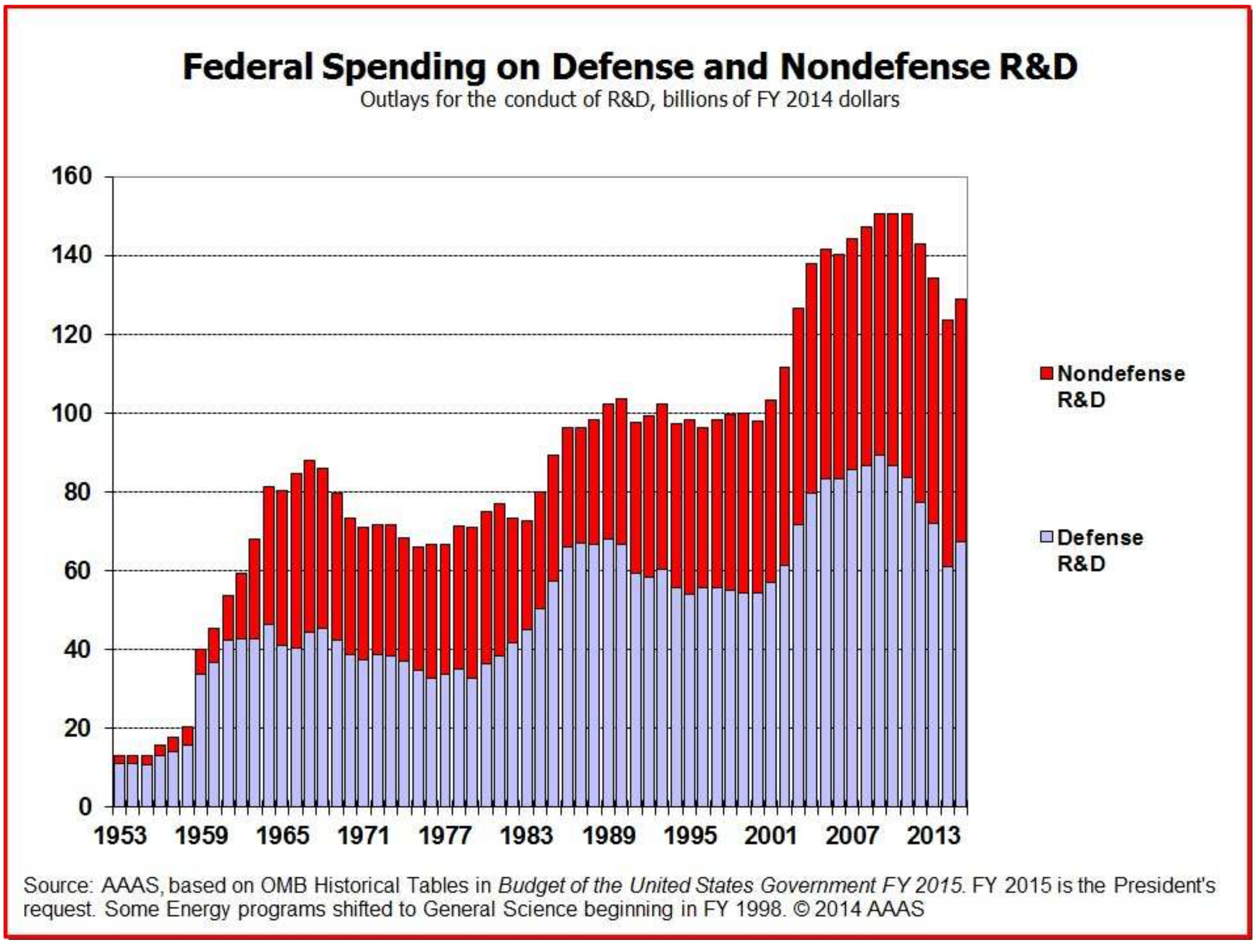
[19] Energy technology is something of an exception, although even in the case of energy technologies, federal investments have been highly controversial and frequently subject to strong political opposition.

[20] This figure is calculated from data in National Science Board, *Science and Engineering Indicators 2014*, Appendix table 4-6

[21] National Science Board, *Science and Engineering Indicators 2014*, page 4-4.

share of total national R&D spending in the U.S. has dropped from more than one-third of the total in the early 1960s to around half of that in 2011.

Second, the percentage of federal R&D devoted to defense has shrunk since the 1950s – although it still remains above 50 percent. The following figure, from the American Association for the Advancement of Science, shows this shift.



Third, total U.S. R&D spending is a declining percentage of overall global R&D spending. We do not have precise figures for the 1950s and 1960s, but it is likely that then the U.S. share of global R&D was well above 50 percent. We do know that in 2001 it was 37 percent, and that it fell to 30 percent in 2011.[22]

In short, at one time DoD R&D funding was a significant share of the planet's R&D funding, whereas now it is a much smaller share.

Changing types of contributions. Beyond these changes in overall R&D spending, the types of contributions made by DoD have also changed over the decades. In the past, there were many examples of major systems being developed for defense and then transferred to the civilian economy. These systems included jet aircraft, radar, computers, the Internet, and GPS technologies. Today, this type of "spin-off" from DoD is less common. In fact, some technologies now move in the opposite direction—from the commercial marketplace to defense applications.

For example, in the 1950s, Boeing based its 707 airliner on a prototype of the KC-135 air tanker that the company developed for the U.S. Air Force. Yet a few years ago, when DoD finally replaced the KC-135, it did not fund a new plane that might later serve as the basis for a new commercial airliner. Instead, its replacement tanker is based on the Boeing 767-200ER, an airliner that was developed in the commercial sector and was introduced into commercial service in 1984, more than 30 years ago. This is a case of the military using a commercial product, not the other way around.[23]

This is not to say that that there are no benefits to commercial aircraft from defense funding. Boeing's use of composite in the 787 Dreamliner no doubt benefited from experience gained in part with using composites over several decades in military airplanes such as the V-22 Osprey and the C-17 transport.[24] But the 787 also illustrates the point that today DoD primarily helps commercial companies by transferring

[22] National Science Board, *Science and Engineering Indicators 2014*, page 4-4.
[23] See http://www.bga-aeroweb.com/Defense/KC-46-Tanker.html.
[24] See http://en.wikipedia.org/wiki/Boeing_787_Dreamliner .

valuable components and materials rather than entire systems such as aircraft, ships, or computers.

Moreover, in some industries commercial companies now possess more advanced technology than do defense contractors. For example, from the 1950s to approximately the 1970s, defense electronics products often were more advanced than commercial electronics. But, since the 1980s commercial electronics products such as semiconductors and computers have been more advanced than counterpart military products, with defense firms focusing on specialized devices that are particularly rugged or are radiation-hardened. And, today, commercial electronics firms innovate much more quickly than defense firms.

Defense technologies may also differ more from civilian technologies than they once did. For example, bomber and transport aircraft in the 1940s and 1950s bore some resemblance to passenger planes. Recent bombers, which have been either stealth or supersonic, bear little resemblance to passenger planes. Innovation in the defense arena has focused on higher performance along such dimensions as speed, maneuverability, and survivability, whereas innovation in commercial airliners has focused on greater efficiency as measured, for example, by costs per seat-mile or per ton-mile of freight.

Changes in defense technology development. In response to these various changes in technologies and markets, defense technology development has changed. Much advanced defense technology development now focuses on systems integration, using components shared with the commercial sector. Much advanced defense technology development is now co-developed with firms in the commercial economy to spur development of technology ecosystems and enable faster development.

Rather than developing technologies solely for defense purposes, DoD (especially DARPA) will seek early commercial applications for a technology so that the commercial sector, with its large markets and faster cycle time, can mature the basic technology, enabling rapid evolution of better and cheaper practical technologies that can be incorporated into defense systems.

Two examples from SRI International are instructive. DoD has sought to provide soldiers with better access to information, and has funded large artificial intelligence projects to bring together voice recognition, speech synthesis, information retrieval, and other functions. While SRI (with others) developed these technologies for DARPA, it was also encouraged to introduce them into the commercial market, both to accelerate the development of the technologies and to provide economic benefits. These efforts resulted in both speech recognition products (through Nuance, a spin-off company) and the Siri i-Phone app. Similarly, DARPA funded robotic surgery as a way to give soldiers wounded in the field access to surgery performed by remote doctors. While the technology was developed for DARPA, DARPA has also encouraged its application in the civilian sector, and the DaVinci surgical system is widely used in civilian hospitals. The further development of the technology will provide benefits to defense applications.

5.5. What are the weaknesses of the DoD system?

While the DoD system has characteristics that are very powerful in developing new advanced technologies, it has weaknesses as well. Overall the DoD procurement system can be slow, expensive, and excessively complicated and bureaucratic. The size of the DoD enterprise alone makes it cumbersome, but its efficiency is also hurt by conflicts among the military services; the Army, Navy, and Air Force are fiercely independent, and each has its own R&D systems, weapons systems, and laboratories that often compete with each other. This rivalry makes it difficult to achieve efficiencies in R&D and procurement.

The efficiency of defense R&D and procurement can also be impaired by narrowly-focused Congressional actions. Military bases, laboratories, and defense contractors provide significant economic benefits to the states and Congressional districts in which they are based, and members of Congress often fight to keep existing bases, laboratories, and production facilities in their districts, even if DoD no longer needs them. As a result, DoD is not always able to take immediate advantage of new developments or must continue to spend precious R&D and/or procurement funds on lower priority projects.

In addition, Army, Navy, and Air Force laboratories are government-owned, government-operated laboratories that share several problems with other government organizations:

- Government salaries make it difficult to attract the best researchers.
- Employment regulations make it difficult to fire unproductive workers.
- National-security based requirements for government laboratory employees to be U.S. citizens mean the laboratories cannot take advantage of immigrant talent.
- Government rules and regulations affecting general operations (such as restrictions on travel) can undermine the efficiency and effectiveness of laboratory researchers.
- Funding of research in government laboratories is less competitive and subject to less peer review than in the civilian sector, which is thought to undermine the quality of the R&D done at the laboratories.

The contractor-operated laboratories (the FFRDCs and UARCs discussed previously) are somewhat better in most of these areas, but still are subject to many regulations and security requirements that can inhibit their performance.

Defense contractors are also viewed as expensive, due to heavy regulations, lack of competition, and a cost-tolerant customer that puts performance ahead of cost. However, that the toleration of high costs is also what make the overall DoD system effective at developing new technologies.

DARPA, it should be noted, avoids many of these problems. It is able to fund the very best researchers, and it quickly discontinues funding to teams that are not successful teams. DARPA is able to fund organizations that employ non-U.S. citizens on many projects, and it has been able to avoid much (but not all) of the bureaucracy that encumbers other Federal agencies. It makes its awards on a highly competitive basis, and its R&D performers must continue to compete in order to receive additional funding.

5.6 What lessons does DoD provide about how government can support commercial technology development?

Taken as whole, the DoD system clearly has strengths and weaknesses as a model for developing commercial technology. It is clearly advantageous to have a system that:

- Links the whole value chain from fundamental research, to advanced technology development, to user applications.
- Is willing to pay a premium price for high performance.
- Has broad technology needs that in some cases align with civilian economy needs.

It is also clear that the DARPA R&D management system has been highly effective. While DARPA stands out within the DoD system for its innovations, it is important to recognize that DARPA is not a complete system by itself. It relies on a base of knowledge, talent, facilities, and even administrative support that is provided by other agencies, and it also has strong connections to its customers in the military services who help define the need for the technologies and support further development.

Most importantly, the DoD experience shows that if governments are willing to make long-term, thoughtful, but also risky investments in new technologies and to turn those new technologies into actual products, then governments can have an important effect on commercial technology and economic growth.

Of course, this conclusion must balanced against both the practical and ideological challenges to having governments perform these roles in ways that are intended to influence commercial markets. DoD's impact on commercial markets is largely an unintended side effect of its determination to develop, build, and use the most technologically advanced products and systems it can. Whether the DoD model could succeed as model for the organization and conduct of R&D intended for commercial markets remains largely an untested idea.