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The Global Research and Development Landscape and Implications for the Department of Defense

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SUMMARY

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For more than 70 years, the technological superiority of the United States military has offset the size and geographic advantages of potential adversaries. The Department of Defense (DOD), due in large part to the magnitude of its investments in research and development (R&D), has driven the global R&D and technology landscape. However, DOD and the federal government more broadly are no longer overriding funders of R&D, and this shift in support for R&D has substantial implications for how DOD obtains advanced technology and maintains the battlefield overmatch that technology has historically provided.

In 1960, the United States accounted for 69% of global R&D, with U.S. defense-related R&D alone accounting for more than one-third of global R&D (36%). Additionally, the federal government funded approximately twice as much R&D as U.S. business. However, from 1960 to 2016, the U.S. share of global R&D fell to 28%, and the federal government's share of total U.S. R&D fell from 65% to 24%, while business's share more than doubled from 33% to 67%. As a result of these global, national, and federal trends, federal defense R&D's share of total global R&D fell to 3.7% in 2016. This decline resulted primarily from more rapid increases in the R&D of other nations (public and private) and partially from increases in U.S. business R&D and federal nondefense R&D.

Some defense experts and policymakers have recognized the shift in the global R&D landscape and the need for DOD to rely increasingly on technologies developed by commercial companies for commercial markets. Among the challenges DOD faces in acquiring new, innovative technologies and maintaining U.S. military technical superiority are

- developing/modifying organizations and business models to access this technology;
- adapting the DOD business culture to seek and embrace technologies developed outside of DOD, the United States, and its traditional contractor base; and
- finding ways to adapt and leverage commercial technologies for defense applications.

Congress plays a central role in how DOD creates and acquires leading-edge technologies, including establishing and refining the organizational structure of DOD R&D activities, providing policy direction, establishing acquisition policies and authorities, and appropriating funds for R&D and innovation-related activities. Congress and the Administration have undertaken a number of actions to address the perceived decline in technical superiority, including

- establishing the position of the Under Secretary of Defense for Research and Engineering to coordinate DOD's research enterprise, drive the development of key technologies, and create a more agile and innovative department;
- increasing DOD collaboration and engagement with industry and academia. For example, DOD has increased its presence in U.S. commercial technology hubs through the Defense Innovation Unit, established partnership intermediary agreements with various organizations, and co-located DOD research and development personnel at partner institutions across the country; and
- working to alter the culture of DOD to increase the speed technologies are developed, adapted, and acquired, including through the use of other transaction authority.

As DOD implements these reform efforts congressional oversight may include monitoring how effectively DOD is addressing congressional directives and intent to create a more risk tolerant and innovative DOD.

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Introduction

Providing for the national defense is a central concern of Congress, and technological advantage has long provided U.S. forces with a battlefield overmatch, deterring potential conflicts and contributing to decisive U.S. military victories. Underpinning U.S. technological advantage are leading-edge innovations built on a foundation of insights gained from research and development (R&D) activities. Today, many analysts believe that U.S. technological overmatch—and, by extension, national security—is at risk due to a number of factors, including a rapidly evolving global landscape for innovation; changes in the composition of R&D funding; and the increasing technological prowess of potential adversaries. Many policymakers believe that new approaches and mechanisms are required to maintain U.S. technological advantage.

Congress plays a central role in how the Department of Defense (DOD) creates and acquires leading-edge technologies, including establishing and refining the organizational structure of DOD research and development activities,[1] providing policy direction, and appropriating funds for R&D and innovation-related activities. Congress and the Administration have undertaken actions in these areas in an effort to ensure that the United States maintains superiority over its potential adversaries.

This report provides an overview of the changes that have occurred in the global R&D landscape, the Administration's policies and perspectives on how to maintain U.S. military technological leadership, actions taken by Congress, and potential issues for consideration.

The Global R&D Landscape, Past and Present

Prior to the 1940s, the United States depended on Europe as a major source of scientific capital.[2] World War II (WWII) initiated a vastly expanded role for the U.S. government in funding, administering, and conducting research and development. In support of the war effort, new offices were established at the highest levels of the federal government to support the planning and oversight of scientific and technological efforts. President Franklin Roosevelt created the U.S. Office of Scientific Research and Development (OSRD) by executive order in June 1941 to ensure "adequate provision for research on scientific and medical problems relating to the national defense."[3]

The R&D managed by OSRD contributed to the Allied victory in WWII in a number of ways. Among its best known achievements were the development of atomic weapons under the Manhattan Project and the development of radar. Several of today's largest and most prestigious U.S. national laboratories have their roots in these efforts.[4]

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[1] The phrase "research and development" is used throughout this report. The Department of Defense has traditionally included "testing and evaluation" (T&E) funding together with R&D funding in what it refers to collectively as RDT&E. Recent changes in U.S. reporting of federal R&D funding exclude some funding for late-stage T&E activities. These changes and their underlying rationale are discussed in CRS Report R45150, *Federal Research and Development (R&D) Funding: FY2019*, coordinated by John F. Sargent Jr.

[2] Office of Scientific Research and Development, Department of Defense, *Science: The Endless Frontier*, July 1945, https://www.nsf.gov/about/history/vbush1945.htm#transmittal.

[3] Executive Order 8807, "Establishing the Office of Scientific Research and Development," issued by President Franklin D. Roosevelt, June 28, 1941, http://www.presidency.ucsb.edu/ws/?pid=16137.

[4] National laboratories with roots in World War II include Lawrence Berkeley National Laboratory, Los Alamos National Laboratory, Sandia National Laboratories, Oak Ridge National Laboratory, Argonne National Laboratory, and

In light of the success of the nation's WWII investments in R&D, President Roosevelt sent a letter to OSRD Director Vannevar Bush in November 1944 requesting recommendations on the future of the nation's scientific enterprise, including what government could do to aid the research activities of public and private organizations.[5] With the death of President Roosevelt in April 1945, Bush directed his response to President Harry Truman in the form of a report, *Science: The Endless Frontier*. The report asserted the need for, value of, and rationale for an expanded federal role in supporting R&D and the development of scientific talent to meet societal needs. The report provided specific recommendations for federal government action.

In his report, Bush asserted that "science is a proper concern of government" and advocated for a strong and steady federal government commitment to scientific research to "insure our health, prosperity, and security as a nation in the modern world." The report stated that "scientific progress is essential" and must be "continuous and substantial" to enable

> more jobs, higher wages, shorter hours, more abundant crops, more leisure for recreation, for study, for learning how to live without the deadening drudgery which has been the burden of the common man for ages past … for higher standards of living … the prevention and cures of diseases … conservation of our limited national resources, and … means of defense against aggression.[6]

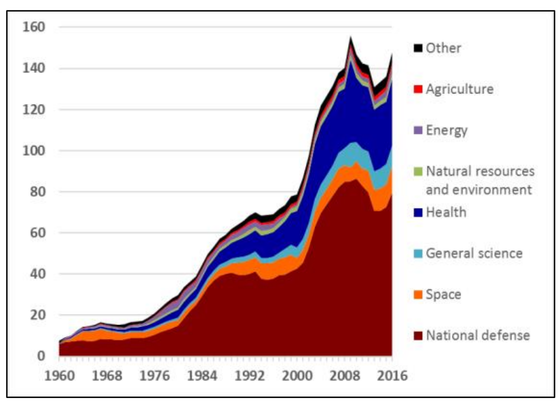
In particular, the report called for "extend[ing federal] financial support to basic medical research in the medical schools and in universities," "more adequate military research in peacetime," and for the public welfare, which the report described in terms of full employment through the creation of "new jobs…new and better and cheaper products…[and] plenty of vigorous new enterprises." The report asserted that this required the United States to create its own scientific capital, turning away from U.S. pre-war reliance on Europe for such knowledge.

While its recommendations were not implemented in their entirety, *Science: The Endless Frontier* served as a blueprint for a greatly expanded federal role in funding R&D, including the establishment of the National Science Foundation and increased funding for federal laboratories, private industry, U.S. universities, and other nonprofit organizations.

Federal R&D funding as a share of total U.S. R&D grew from 53.9% in 1953 to 65% by 1960, peaking at 67% in 1964. Between 1953 and 1960, federal R&D funding more than tripled in current dollars, and by FY1966 it

Figure 1. Federal R&D Funding, by Budget Function, FY1960-FY2016

(in billions of current dollars)



Source: National Science Foundation, Federal Research and Development by Budget Function, FY2016-2018, April 24, 2018.

Ames Laboratory. Some of these laboratories and their forerunners existed on a smaller scale prior to the war.

[5] Office of Scientific Research and Development, Department of Defense, *Science: The Endless Frontier*, July 1945.

[6] Ibid.

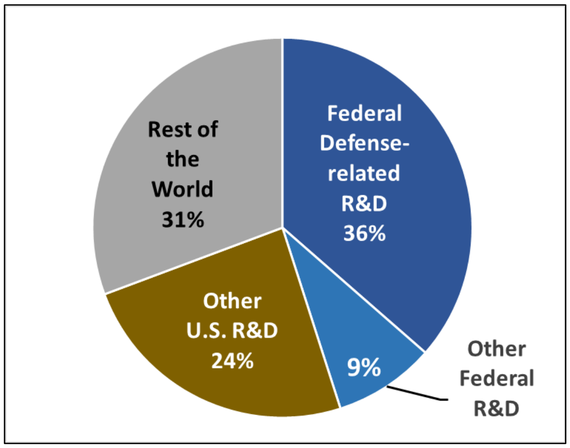
had quintupled.[7] From 1955 to 1966,[8] the vast majority (81%) of the growth in federal R&D funding was for national defense (42% of the growth) and space flight (39% of the growth).[9] (See **Figure 1** for illustration of federal R&D funding by budget function, current dollars, FY1960-FY2016.)

U.S. Post-World War II Dominance in Global R&D

Following WWII, with most of the developed world still recovering from the devastation of the war and with rapid growth in U.S. government and private investment in R&D, the United States came to dominate global R&D spending. As illustrated in **Figure 2**, in 1960, the United States accounted for 69% of global R&D, with U.S. defense-related R&D alone accounting for more than one-third of the global total.

During this period, DOD investments in R&D shaped technology development paths in many fields. Nevertheless, despite rapid real growth in federal defense R&D funding over the next six decades, the U.S. share of global R&D declined substantially.

Figure 2. Global R&D Expenditures, 1960



Source: Based on data from U.S. Department of Commerce, Office of Technology Policy, *The Global Context for U.S. Technology Policy*, Summer 1997.

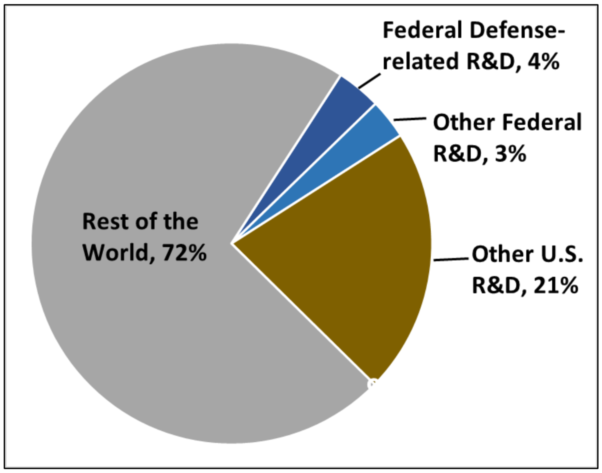
[7] CRS analysis of data published by the National Science Foundation in *National Patterns of R&D Resources: 2015-16 Data Update*, NSF 18-309, May 2018, https://www.nsf.gov/statistics/2018/nsf18309/.

[8] Federal R&D funding data by budget function is not available prior to 1955.

[9] CRS analysis of data published by the National Science Foundation in *Federal R&D Funding, by Budget Function: Fiscal Years 2016–18*, Table 6, April 24, 2018, https://www.nsf.gov/statistics/2018/nsf18308/#chp2.

Despite U.S. R&D Growth, U.S. Share of Global R&D Has Fallen

Figure 3. Global R&D Expenditures, 2016



Source: U.S. data from NSF, *Federal R&D Funding, by Budget Function: Fiscal Years 2015–17,* December 13, 2016, and National Science Foundation, *InfoBrief: U.S. R&D Increased by $20 Billion in 2015, to $495 Billion; Estimates for 2016 Indicate a rise to $510 Billion*, December 14, 2017. Rest of the World share from CRS analysis of OECD data.

As illustrated in **Figure 3**, by 2016 the U.S. share of global R&D had dropped from 69% to 28%.[10] The decline resulted from rapid growth in public and private R&D spending by other nations, even as U.S. R&D expenditures since 1960 grew by a factor of five in constant dollars, and more than 37 times in current dollars.[11]

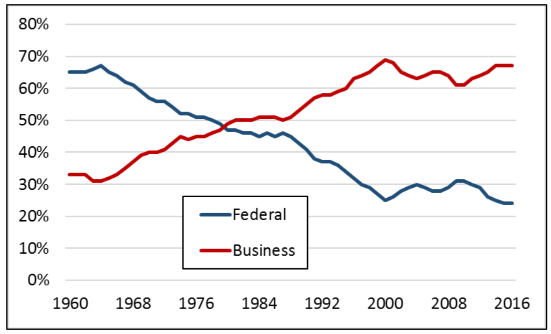
[10] 2016 is the latest year for which comprehensive data are available from the Organisation for Economic Cooperation and Development (OECD) on national research and development expenditures.

[11] National Science Foundation in *National Patterns of R&D Resources: 2015-16 Data Update*, May 2018.

Decline in Federal Share of U.S. R&D, Increase in Business Share

In the early 1960s, the federal government funded approximately twice as much R&D as U.S. business and thus played a substantial role in driving the direction of U.S. and global technology development. However, from 1960 to 2016, the federal government's share of total U.S. R&D fell from 65% to 24%, while business's share more than doubled from 33% to 67%.[12] (See **Figure 4**.) Again, the decline in the federal government's share of total U.S. R&D funding did not result from a decline in federal R&D funding, which more than doubled in constant dollars, but from much faster growth in business R&D funding (which grew by nearly 12 times) and other nonfederal sources of R&D funding. See **Figure 5**. Today, U.S. business funds nearly three times as much R&D as the federal government.

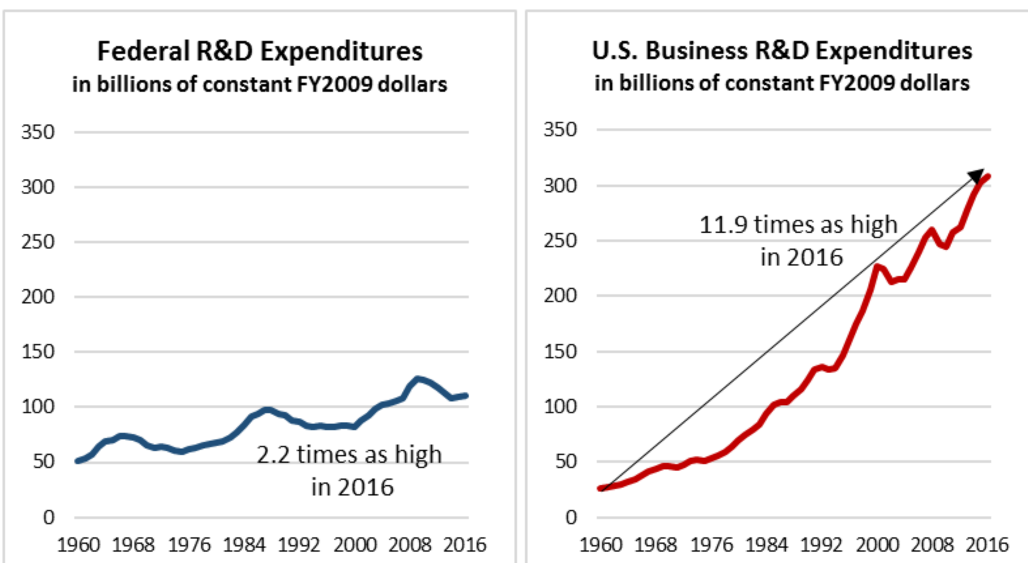
Figure 4. Federal Government and Business Expenditures on R&D, 1960-2016



Source: National Science Foundation, *National Patterns of R&D Resources: 2015-16 Data Update*, NSF 18-309.

This transformation has had, and continues to have, implications for federal R&D strategy and management.

Figure 5. Growth in Federal and U.S. Business R&D Expenditures, 1960-2016



Source: National Science Foundation, *National Patterns of R&D Resources: 2015-16 Data Update*, May 2018.

[12] National Science Foundation in *National Patterns of R&D Resources: 2015-16 Data Update*, May 2018.

Decline in Defense Share of Federal R&D

In addition to the decline in the U.S. share of global R&D, and the decline in the federal share of U.S. R&D during this period, federal funding for defense R&D as a share of total federal R&D declined from 81% to 54% between 1960 and 2016. Once again, federal R&D grew, but nondefense R&D (e.g., general science, space flight, energy, natural resources, transportation) grew faster.[13] As a result of these global, national, and federal trends, federal defense R&D's share of total global R&D fell from 36% in 1960 to 3.7% in 2016.

For more than 70 years, U.S. military technological superiority has provided U.S. and allied troops with superior weapons and systems, offsetting the size and geographical advantages of potential adversaries. The decline in federal defense R&D funding as a share of global R&D has substantial implications for how the Department of Defense obtains advanced technology and maintains the battlefield overmatch that technology has historically provided.

Competitive Drivers of Commercial R&D: Implications for DOD

Whereas decisions made by the President and Congress determine the level of federal defense R&D funding, business R&D is driven largely by commercial opportunities. Lucrative, large, and expanding markets, both current and potential, drive commercial development in fields such as artificial intelligence, computer processors, robotics, software, and advanced materials—fields of substantial importance to 21st century military applications.

Commercial markets drive competition among firms, provide substantial revenues, and induce investors to fund new market entrants. Competitors reinvest a portion of revenues from earlier innovations to achieve further technological advances and to improve their market positions, sometimes managing multiple generations of a technology (e.g., one generation in current production, one in testing and evaluation, and one in advanced research). In today's commercial environment, the pace and cost of innovation may exceed what the federal government can sustain on its own, especially given the expansive scope and number of technologies DOD uses in its weapons, systems, and infrastructure.

Some defense policymakers have recognized DOD's increasing reliance on technologies developed by commercial companies for commercial markets. Among the challenges DOD faces are developing/modifying its current organizations and business models to access this technology; adapting the DOD business culture to seek and embrace technologies developed outside of DOD and its traditional contractor base; and finding ways to adapt and leverage commercial technologies for defense applications. See box items, "Artificial Intelligence: DOD and Google: Are There Social and Ethical Barriers to Engaging with U.S. Technology Companies?" and "Computer Chips: Too Costly for Commercial Chipmakers to Meet DOD Needs?" below for illustrative examples of the challenges DOD faces engaging with commercial companies.

[13] CRS calculations using data from National Science Foundation, *Federal R&D Funding, by Budget Function: Fiscal Years 2016–18,* NSF 18-308, April 24, 2018, https://www.nsf.gov/statistics/2018/nsf18308/#chp2. According to the National Science Foundation, the national defense budget function includes Department of Defense military activities and Department of Energy atomic energy defense programs; some years also include defense-related R&D in the Department of Homeland Security and the Department of Justice.

Concerns About U.S. Competitiveness: Past and Present

Concerns about declining U.S. economic competitiveness and technological leadership—and their potential implications for economic growth, industrial productivity, employment, standard of living, and national security—are not new.

Following WWII, America's new-found global technological leadership and industrial capabilities contributed to strong U.S. economic growth, low unemployment rates, and improvements in the standard of living for Americans.

However, in the late 1970s and early 1980s, the United States faced growing trade deficits; slowing rates of productivity growth; increased competition in industries such as automobiles, steel, consumer electronics, and semiconductors; lower corporate profits; plant closings; and job losses.

Congress responded, in part, to these challenges by enacting legislation intended to improve U.S. development and commercialization, including the Stevenson-Wydler Technology Innovation Act of 1980 (P.L. 96-480), Bayh-Dole Act (P.L. 96-517), Small Business Innovation Development Act of 1982 (P.L. 97-219), Cooperative Research and Development Act of 1984 (P.L. 98-462), and Federal Technology Transfer Act of 1986 (P.L. 99-502). (See **Appendix** for more detailed information on these acts.)

Toward the end of the 1980s, the challenge to U.S. competitiveness became more specific. Japan's economic success, export penetration of U.S. markets, industrial strength, innovative manufacturing approaches, and technological capabilities gave rise to increasing concerns about the competitiveness of U.S. industry. Some policymakers and analysts asserted that Japan's success was based on government-coordinated industrial policies and trade advocacy (this cooperation was sometimes referred to as "Japan, Inc.", a term suggesting Japan's government and private sector acted as a single entity), unfair policies and practices, closed or difficult to access markets, appropriation of U.S. technologies through reverse engineering, and lack of reciprocal access to science and technology programs. Others asserted that Japan's economic system, including the industrial organizations known as keiretsu,[14] offered a superior competitive structure that the U.S. government and American industry should emulate. Some saw the perceived loss of U.S. competitiveness as attributable to other factors as well, such as industrial complacency driven by a large domestic market that resulted in a failure to continue to innovate and a lack of support for small and medium-size manufacturers.

Congress responded to concerns about Japan's rising technological and industrial strength and its potential implications for the United States, in part, by enacting legislation such as the Omnibus Trade and Competitiveness Act of 1988 (P.L. 100-418) and the National Competitiveness Technology Transfer Act of 1989 (P.L. 101-189). (See **Appendix** for more detailed information on these and similar acts.)

In the mid-1980s, the U.S. semiconductor industry became a focus of concern about America's loss of technological leadership. During the 1980s, the industry experienced a steep decline in its

[14] Keiretsu are very large, informal, vertically linked or horizontally linked amalgamations of businesses with interlocking business relations, including cross-shareholdings and shared members of their boards of directors. These organizations can include manufacturers, suppliers, and distributors, and generally have a bank at its core. The Japanese pre-WWII zaibatsu system is the predecessor to keiretsu. Korean chaebol have characteristics similar to keiretsu.

share of U.S. and global markets due to competition from Japanese producers. In 1986, Japan surpassed the United States in commercial semiconductor chip production;[15] the U.S. share of the world market for merchant producers fell from 100% in 1975 to less than 5%;[16] and by 1986, Japanese firms accounted for 65% of the DRAM (dynamic random-access memory) chips sold in the United States, and more than 80% of the global market.[17]

The Department of Defense, a long-time supporter and user of semiconductor technology, was particularly concerned about the implications of a loss of U.S. leadership in semiconductors. In 1987, a report by the Defense Science Board (DSB), a panel of government and industry experts, concluded that "U.S. leadership in semiconductor manufacturing is rapidly eroding," and that not only was "the manufacturing capacity of the U.S. semiconductor industry … being lost to foreign competitors, principally Japan…, but of even greater long-term concern, that technological leadership is also being lost."[18] The DSB proposed the establishment of a public-private semiconductor manufacturing technology R&D partnership supported equally by DOD and the semiconductor industry. The partnership was to focus on next generation semiconductor technology (the 64 megabit DRAM), and include support for a manufacturing facility.

In December 1987, Congress authorized DOD financial support of up to $100 million for the SEMATECH consortium,[19] while limiting federal, state, and local government support to no more than 50% of total funding. Concerned about supporting a government-industry semiconductor facility that would manufacture DRAMs for the commercial market, Congress directed that SEMATECH funding be used for the conduct of research on advanced semiconductor manufacturing techniques, and for the development of manufacturing techniques for a variety of semiconductor products.[20]

In late 1987, SEMATECH was established under a memorandum signed by representatives of DOD and 11 U.S. semiconductor companies. Congress provided $100 million for SEMATECH in FY1988 and a total of approximately $870 million through FY1996 when funding ended. These funds were matched by the industry partners. While some analysts assert that SEMATECH played an important role in preserving the U.S. semiconductor's competitive position during this period, others disagree.

Concerns about Japanese dominance in technology-intensive industries have diminished in the interceding decades. While Japanese firms are formidable competitors in a number of industries (e.g., machine tools, robotics, automobiles, consumer products, steel, semiconductors), they have not become the economic juggernaut that some feared would seize global leadership across a vast swath of technologies and undermine U.S. economic prosperity.

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[15] Department of Commerce, *1987 U.S. Industrial Outlook*, 1987, pp. 28-29, as cited in Glenn J. McLoughlin and Nancy R. Miller, *The U.S. Semiconductor Industry and the Sematech Proposal*, 87-254 SPR, Congressional Research Service, April 23, 1987.

[16] Ibid., pp. 32-34–32-35; Department of Defense, Defense Science Board, *Report of the Defense Science Board Task Force on Semiconductor Dependency*, 1987, p. 5, as cited in Glenn J. McLoughlin and Nancy R. Miller, *The U.S. Semiconductor Industry and the Sematech Proposal*, 87-254 SPR, Congressional Research Service, April 23, 1987.

[17] Arthur L. Robinson, "A 16 Megabit Memory Chip from Japan," *Science*, vol. 235, no. 4794 (May 13, 1987), pp. 1324-1325.

[18] Department of Defense, Defense Science Board, Task Force on Semiconductor Dependency, *Report of the Defense Science Board Task Force on Semiconductor Dependency*, January 1987.

[19] The name SEMATECH was derived from semiconductor manufacturing technology.

[20] P.L. 100-180 (National Defense Authorization Act for Fiscal Years 1988 and 1989).

In more recent years, some have expressed concerns about the competitive challenges posed by certain countries in a narrower swath of industries. For example:

- South Korea experienced a swift rise from an agriculture-based economy in the 1960s to an industrial economy built, in part, on advanced technological capabilities. Today, South Korea has thriving consumer electronics and automobile industries. Some credit South Korea's success to export-oriented policies, improvements in its business environment (e.g., ease of starting a business, enforcing contracts, getting electricity), and policies to incentivize innovation (e.g., South Korea leads the world in R&D intensity, defined as R&D spending as a percentage of gross domestic product).[21]
- India had rapid growth in the 1990s and 2000s in fields such as software; information technology services; and information technology-enabled industries (ITES), including outsourcing of business processes (e.g., human resources, finance, accounting, customer service). India's population (1.282 billion in 2017, second only to China's population of 1.379 billion)[22] might also provide it with a competitive advantage in creating and testing products tailored to consumers in developing countries and to build market share in that demographic through domestic sales.

As with Japan, South Korea and India have been successful in advancing their industries and improving their standards of living, but neither has become an across-the-board economic juggernaut that threatens U.S. technological and economic leadership.

None of these countries posed or pose both a broad, multi-industry technology-based competitiveness challenge to the United States as well as a near-peer national security challenge. These countries also did not or do not have an integrated civilian-military strategy for achieving global technological dominance. Today, China has each of these elements. The leading role of the private sector in driving advances in the technologies (e.g., artificial intelligence, autonomous systems, robotics, quantum computing, advanced gene editing) that are expected to be critical to both commercial competitiveness and military strength has given rise to concerns that are discussed in the next section.

Rise of China in R&D

A primary challenge to American military technological preeminence is the emergence of China as a potential military adversary and as a science and technology powerhouse. The President's *National Security Strategy* and the *National Defense Strategy* echo this theme. And in June 2018, several senior DOD officials raised this concern in congressional testimony:

> The Department of Defense is facing an unprecedented threat to its technological and industrial base. Continued globalization and our open society, both in academia and business, has offered China and others access to the same technology and information that is critical to the success of our future warfighting capabilities. China is making significant and targeted investments in the same technologies of interest to the Department.… China

[21] Federal Reserve Bank of St. Louis, On the Economy Blog, Ana Maria Santacreu and Heting Zhu, "How Did South Korea's Economy Develop So Quickly?", March 20, 2018, https://www.stlouisfed.org/on-the-economy/2018/march/how-south-korea-economy-develop-quickly.

[22] Central Intelligence Agency, *The World Factbook* online, https://www.cia.gov/library/publications/the-world-factbook/geos/ch.html. Population data estimated as of July 2017.

> has made it a national goal to acquire foreign technologies to not only advance its economy, but also to use these technologies to advance its military capabilities, and it is doing so through both licit and illicit means.[23]

China's emergence as a global science and technology leader is evidenced in part by its rising position among nations in the funding of R&D. China's share of global R&D rose from 4.9% in 2000 to 25.1% in 2016. During this same period, the United States, Japan, and Germany saw their collective share of global R&D fall from 62.6% to 44.3%.

Moreover, while the United States remained the world's single largest funder of R&D in 2016, spending 13% more than China (see **Table 1**), China's R&D funding has been growing at a much more rapid pace. As a result, China's R&D expenditures passed Germany's in 2004 and Japan's in 2009 (see **Figure 6**). If China and the United States continue to grow at the same rates as their recent averages, China may soon pass the United States in R&D spending.[24]

Table 1. Nations with the Largest Gross Expenditures on R&D, 2016

(in billions of current purchasing power parity (PPP) U.S. dollars)

Nation	Amount	Share of Global Total
United States	$511.1	28.4%
China	451.2	25.1%
Japan	168.6	9.4%
Germany	118.2	6.6%
South Korea	79.4	4.4%
France	62.2	3.5%
United Kingdom	47.2	2.6%
Russia	39.9	2.2%
Taiwan	35.8	2.0%
Italy	29.9	1.7%

Source: CRS analysis of OECD 2016 Gross Expenditures on R&D (GERD) data accessed October 23, 2018.

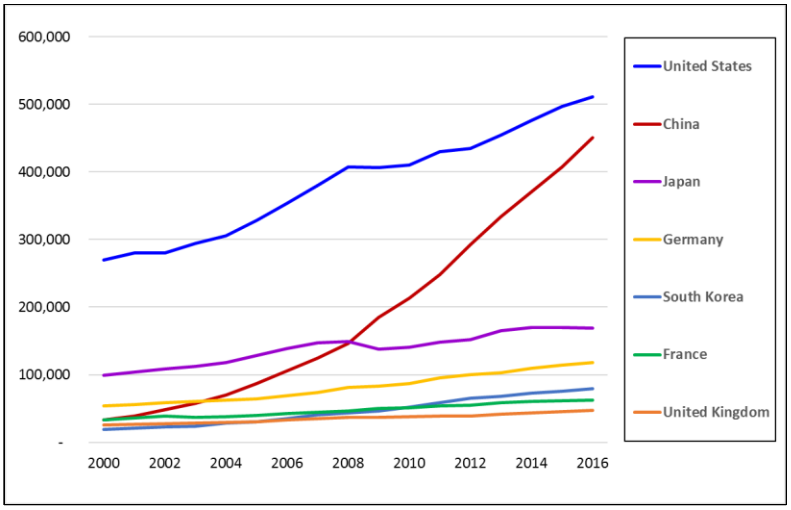
Notes: Purchasing power parity is an economic analysis tool used to adjust international currencies to a common currency (in this case, U.S. dollars) based on each currency's domestic purchasing power. For the purpose of this analysis, global R&D includes all OECD countries, plus Argentina, China, Romania, Russia, Singapore, South Africa, and Taiwan.

23 Joint witness statement of Michael D. Griffin, Undersecretary of Defense for Research and Engineering; Kari A. Bingen, Deputy Undersecretary of Defense for Intelligence; Eric Chewning, Deputy Assistant Secretary of Defense for Manufacturing and Industrial Base Policy; and Anthony M. Schinella, Office of the Director of National Intelligence before the House Committee on Armed Services hearing on *Military Technology Transfer: Threats, Impacts, and Solutions for the Department of Defense*, 115th Cong., June 21, 2018.

24 CRS calculation based on analysis of OECD R&D data. The United States compound annual growth rate (CAGR) for R&D between 2011 and 2016 was 3.5%; China's CAGR was 12.7%. Applying these percentages for two years to the 2016 levels for these countries would increase U.S. R&D funding to $547.8 billion and China R&D funding to $573.4 billion in 2018. Actual 2018 figures are not yet available.

Figure 6. Gross Expenditures on R&D for Selected Nations, 2000-2016

(in millions of PPP dollars)

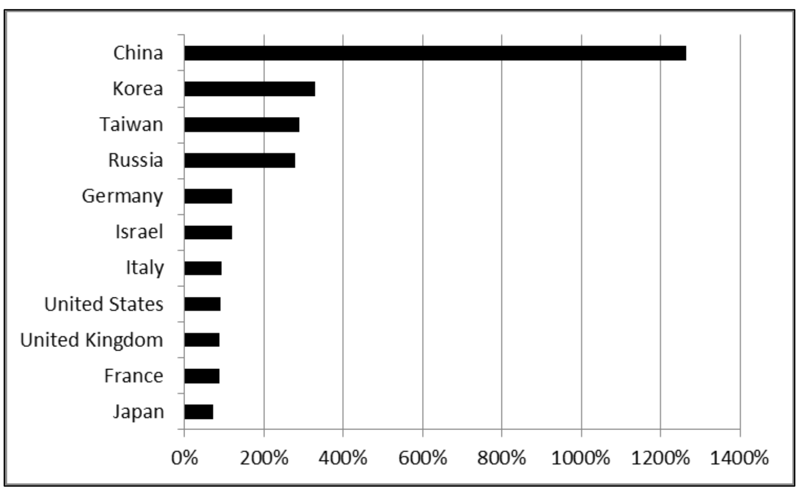


Source: CRS analysis of OECD GERD data measured in purchasing power parity dollars.

Notes: PPP = purchasing power parity

Figure 7 shows the percentage growth in R&D expenditures for selected nations between 2000 and 2016, as reported to the OECD. It further illustrates the rapid growth of China's R&D investments relative to those of other nations. During this period, China's R&D grew by 1,264% while U.S. R&D grew by 90%. In absolute terms, China's R&D grew by $418.1 billion, while U.S. R&D growth was $241.6 billion and R&D growth of the 28 countries of the European Union combined was $208.8 billion.[25]

Figure 7. Growth in Gross Expenditures on R&D for Selected Nations, 2000-2016



Source: CRS analysis of OECD GERD data measured in purchasing power parity dollars.

Though the growth shown in **Figure 7** is for total R&D funding, only a portion of which is defense-related, these trends have raised concerns among many defense analysts and senior DOD

[25] CRS analysis of OECD 2016 Gross Expenditures on R&D (GERD) data.

leaders. For example, Obama Administration Under Secretary of Defense Frank Kendall testified in January 2015 that

> [O]ver the past few decades, the U.S. and our allies have enjoyed a military capability advantage over any potential adversary.... The First Gulf War put this suite of technologies and the associated operational concepts on display for the world to observe and study. The First Gulf War also marked the beginning of a period of American military dominance that has lasted about a quarter of a century and served us well in several conflicts. We used the same capabilities, with some notable enhancements, in Serbia, Afghanistan, Libya and Iraq. It has been a good run, but the game isn't one sided, and all military advantages based on technology are temporary.... The rise of foreign capability, coupled with the overall decline in U.S. research and development investments, is jeopardizing our technological superiority.[26]

Despite continued U.S. science and technology (S&T) leadership, it is widely asserted that the gap between the United States and China has been decreasing in recent years. In 2015, Michael Dumont, then-Principal Deputy Assistant Secretary of Defense for Special Operations/Low Intensity Conflict, reportedly stated

> Many of our adversaries have acquired, developed and even stolen technologies that have put them on somewhat equal footing with the West in a range of areas.... [T]he U.S. government no longer has the leading edge developing its own leading edge capabilities, particularly in information technology.[27]

China's Approaches to Capturing Global Technology Leadership

Funding domestic R&D is only one pillar in China's strategy to obtain global technology leadership. A 2018 report published by DOD's Defense Innovation Unit (DIU) asserts that China is engaged in a deliberate, sophisticated, long-term, and integrated approach to achieving this end, by both legal and illegal means.[28]

According to the report, China seeks to reduce reliance on foreign technology, to develop indigenous innovation capabilities, and to close the military gap with the United States. The report states that China's focus includes a number of dual-use technologies, including artificial intelligence (AI), autonomous systems, robotics, nanotechnology, augmented reality/virtual reality (AR/VR), financial technology, and gene editing. Further, the report states that China's strategy for achieving technological leadership includes the following tools:

- theft of intellectual property through industrial espionage and cybertheft;
- foreign direct investment;
- China-based venture capital (some government-sponsored) targeting early stage technology companies;
- investment by Chinese companies in U.S. venture-backed deals;
- private equity investments;

[26] Written Statement of then-Under Secretary of Defense Frank Kendall, U.S. Congress, House Committee on Armed Services, *A Case for Reform: Improving DOD's Ability to Respond to the Pace of Technological Change*, 114th Cong., 1st sess., January 28, 2015.

[27] Stew Magnuson, "DOD Official: Government Has Lost its Technological Edge Over Opponents," *National Defense Magazine*, January 27, 2015, http://www.nationaldefensemagazine.org/Pages/default.aspx.

[28] Department of Defense, Defense Innovation Unit Experimental, *China's Technology Transfer Strategy: How Chinese Investments in Emerging Technologies Enable a Strategic Competitor to Access the Crown Jewels of U.S. Innovation*, January 2018.

- investments through special purpose vehicles that are designed to obscure the source of capital;
- acquisition of companies;
- access to open source information;
- Chinese-based technology transfer organizations;
- U.S.-based associations sponsored by the Chinese government to recruit talent;
- sending Chinese students to study science, technology, engineering, and mathematics (STEM) in the United States and other Western countries (25% of U.S. STEM graduate students are Chinese nationals); and
- acquisition of technical and business expertise from U.S. firms.

To achieve its goal of technological leadership, China has put forth a number of national plans and initiatives to guide its public and private activities, including *13th Five Year Plan for Economic and Social Development of the People's Republic of China (2016-2020)*,[29] *Made in China 2025,*[30] *Mega Project Priorities,*[31] and *Project 863*.[32]

Trump Administration Policies and Perspectives

The *National Security Strategy of the United States* (NSS),[33] released by President Donald Trump in December 2017, and the *National Defense Strategy of the United States of America: Sharpening the American Military's Competitive Edge* (NDS),[34] released by Defense Secretary Jim Mattis in January 2018, offer insights into the Administration's perspectives on the changing global R&D landscape and provide a strategic framework for its policies and approaches to ensuring U.S. technological dominance on the battlefield.

[29] People's Republic of China, *13th Five Year Plan for Economic and Social Development of the People's Republic of China (2016-2020)*, http://en.ndrc.gov.cn/newsrelease/201612/P020161207645765233498.pdf.

[30] People's Republic of China, State Council, *Made in China 2025*, available from IoT One, a Shanghai-based organization supporting Internet of Things innovation, at http://www.cittadellascienza.it/cina/wp-content/uploads/2017/02/IoT-ONE-Made-in-China-2025.pdf.

[31] The Mega Projects concept was introduced in China's *The National Medium- and Long-Term Program for Science and Technology Development (2006-2020): An Outline* (produced by China's State Council), http://www.cistc.gov.cn/oa/file/download.asp?id=6298. According to the European Union report *Advance EU Access to Financial Incentives for Innovation in China: Guide for EU Stakeholders on Chinese National STI Funding Programmes*, there are 16 science and technology Mega Projects, 10 of which involve civilian applications and 6 of which are focused on civil-military integration or pure military applications.

[32] People's Republic of China, Ministry of Science and Technology, Project 863 (also referred to as the 863 Program), http://www.most.gov.cn/eng/programmes1.

[33] The White House, *National Security Strategy of the United States*, December 2017, https://www.whitehouse.gov/wp-content/uploads/ ... /NSS-Final-12-18-2017-0905.pdf.

[34] Department of Defense, *Summary of the 2018 National Defense Strategy of the United States: Sharpening the American Military's Competitive Edge*, January 2018, https://dod.defense.gov/Portals/1/ ... /2018-National-Defense-Strategy-Summary.pdf. The *2018 National Defense Strategy* is classified; the document linked above is the unclassified summary of the report. For more information on the *National Defense Strategy*, see CRS Report R45349, *The 2018 National Defense Strategy: Fact Sheet*, by Kathleen J. McInnis, and CRS Insight IN10855, *The 2018 National Defense Strategy*, by Kathleen J. McInnis.

National Security Strategy

The NSS addresses both commercial and national defense issues in the overall context of national security. Among the elements addressed in the NSS are globalization and its implications, increased reliance on commercial innovation to meet national needs, the need for speed to maintain America's commercial and defense competitiveness, and the need to protect the elements of our national innovation system from foreign competitors and adversaries.

Globalization of R&D and Its Implications

The NSS recognizes the globalization of scientific and technological innovation and asserts the importance to DOD and other federal agencies of acquiring a better understanding of global science and technology trends and their potential effects on U.S. strategies, policies, and programs. According to the NSS, "to retain U.S. advantages over our competitors, U.S. Government agencies must improve their understanding of worldwide S&T trends and how they are likely to influence—or undermine—American strategies and programs."[35]

Increased Reliance on Commercial Innovators, Nontraditional Defense Suppliers

The NSS acknowledges the leading role industry plays in the development of new technologies, especially those vital to the national defense, and asserts a need for the federal government to more effectively tap these capabilities:

> The U.S. Government will use private sector technical expertise and R&D capabilities more effectively. Private industry owns many of the technologies that the government relies upon for critical national security missions. The Department of Defense and other agencies will establish strategic partnerships with U.S. companies to help align private sector R&D resources to priority national security applications.
>
> We must eliminate bureaucratic impediments to innovation and embrace less expensive and time-intensive commercial off-the-shelf solutions. Departments and agencies must work with industry to experiment, prototype, and rapidly field new capabilities that can be easily upgraded as new technologies come online. [36]

In testimony before the Senate Armed Services Committee, Defense Secretary Mattis stated that DOD would "leverage commercial research and development to provide leading edge capabilities to the Department while encouraging emerging nontraditional technology companies to focus on DOD-specific problems." Secretary Mattis also reaffirmed DOD's commitment to continuing its investments in basic research and in the Defense Advanced Research Projects Agency's (DARPA's) efforts to develop technologies for revolutionary, high-payoff military capabilities.[37]

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[35] The White House, *National Security Strategy*, December 2017, p. 20, https://www.whitehouse.gov/wp-content/uploads/2017/12/NSS-Final-12-18-2017-0905-2.pdf.

[36] Ibid., pp. 21 and 29.

[37] Testimony of Secretary of Defense Jim Mattis before the Senate Committee on Armed Services, hearing on the "Department of Defense Budget Posture," April 26, 2018, https://www.armed-services.senate.gov/download/mattis_04-26-18.

The Need for Speed

Recognizing that potential military adversaries may have access to the same suite of commercially available technologies as DOD does, the NSS places a premium on speed in the development, adaptation, and acquisition of technologies, as well as in bringing them to the warfighter in the form of new tools and weapons. According to the NSS, "the United States must regain the element of surprise and field new technologies at the pace of modern industry. Government agencies must shift from an archaic R&D process to an approach that rewards rapid fielding and risk taking."[38]

In testimony before the House Armed Services Committee, Secretary Mattis stated that DOD is transitioning to a culture of performance and affordability "that operates at the speed of relevance," and that the department is prioritizing speed of delivery, along with continuous adaptation and frequent modular upgrades.[39]

In testimony before the House Armed Services Committee, Under Secretary of Defense for Research and Engineering Mike Griffin discussed the implications of commercial firms leading technology development in disciplines that will play an increasingly important role in U.S. national security. He said this situation could lead to a reduction in the U.S. military's technological advantage over potential adversaries and the need for DOD to develop and implement new approaches to capitalize on and leverage commercial research. Because of this he emphasized the importance of speed in innovation and in the delivery of military capabilities to national security:

> The incremental democratization of technology has fostered global and easy access to cutting edge capabilities, which has in turn contributed to the ability of our adversaries to achieve technology parity. As a result, our military's advanced technical capabilities and unmatched technological superiority is being challenged by the investments of competing powers. Given the leveled playing field, speed in developing new technologies and delivering capabilities to the warfighter is more critical now than ever.
>
> We must be willing and able to tap into commercial research, recognize its military potential, and leverage it to develop new capabilities, while also accounting for the operational and organizational constructs to employ them faster than our competitors.[40]

Protection of the National Security Innovation Base

The NSS also asserts the importance of defending what it calls the National Security Innovation Base (NSIB) against adversaries who use both licit (e.g., technology licensing, acquisition of companies) and illicit (e.g., theft of intellectual property) mechanisms "to gain access to fields, experts, and trusted foundries that fill their capability gaps and erode America's long-term competitive advantages."[41] The NSS defines the NSIB as "the American network of knowledge, capabilities, and people—including academia, National Laboratories, and the private sector—that turns ideas into innovations, transforms discoveries into successful commercial products and

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[38] The White House, *National Security Strategy*, p. 21.

[39] Testimony of Secretary of Defense Jim Mattis before the House Committee on Armed Services, February 6, 2018, hearing on "The National Defense Strategy and the Nuclear Posture Review," http://docs.house.gov/meetings/AS/AS00/20180206/106833/HHRG-115-AS00-Wstate-MattisJ-20180206.pdf.

[40] Testimony of Under Secretary of Defense for Research and Engineering Mike Griffin before the House Committee on Armed Services, hearing on "Promoting DOD's Culture of Innovation," April 18, 2018, https://www.armed-services.senate.gov/download/griffin_04-18-18.

[41] The White House, *National Security Strategy*, p. 21.

companies."[42] According to the NSS, "the landscape of innovation does not divide neatly into sectors. Technologies that are part of most weapon systems often originate in diverse businesses as well as in universities and colleges. Losing our innovation and technological edge would have far-reaching negative implications for American prosperity and power."[43]

National Defense Strategy

The National Defense Strategy (NDS) builds on the NSS framework, recognizing the changing global landscape, the increased pace of innovation, increased reliance on commercial technologies to meet defense needs, U.S. adversaries' potential access to these technologies, the potential erosion of U.S. technological advantage, and the need for cultural change within DOD:

> The security environment is also affected by rapid technological advancements and the changing character of war. The drive to develop new technologies is relentless, expanding to more actors with lower barriers of entry, and moving at accelerating speed. New technologies include advanced computing, "big data" analytics, artificial intelligence, autonomy, robotics, directed energy, hypersonics, and biotechnology—the very technologies that ensure we will be able to fight and win the wars of the future. New commercial technology will change society and, ultimately, the character of war. The fact that many technological developments will come from the commercial sector means that state competitors and nonstate actors will also have access to them, a fact that risks eroding the conventional overmatch to which our Nation has grown accustomed. Maintaining the Department's technological advantage will require changes to industry culture, investment sources, and protection across the National Security Innovation Base."[44]

Among its objectives, the NDS reinforces the Administration's priorities for rapid innovation, affordability, changes to the DOD culture, and the importance of the NSIB:

> Continuously delivering performance with affordability and speed as we change Departmental mindset, culture, and management systems; and
>
> Establishing an unmatched twenty-first century National Security Innovation Base that effectively supports Department operations and sustains security and solvency."

The NDS also emphasizes the need for DOD structural and cultural changes to support innovation, and the mandate the department has given to DOD managers to pursue such changes:

> The Department's management structure and processes are not written in stone, they are a means to an end–empowering the warfighter with the knowledge, equipment and support systems to fight and win. Department leaders will adapt their organizational structures to best support the Joint Force. If current structures hinder substantial increases in lethality or performance, it is expected that Service Secretaries and Agency heads will consolidate, eliminate, or restructure as needed. The Department's leadership is committed to changes in authorities, granting of waivers, and securing external support for streamlining processes and organizations…. A rapid, iterative approach to capability development will reduce costs, technological obsolescence, and acquisition risk. The Department will realign incentive and reporting structures to increase speed of delivery, enable design trade-offs in the requirements process, expand the role of warfighters and intelligence analysis throughout the acquisitions process, and utilize nontraditional suppliers. Prototyping and

[42] Ibid.

[43] Ibid.

[44] Department of Defense, Summary of the 2018 National Defense Strategy of the United States of America: Sharpening the American Military's Competitive Edge," January 2018, p. 3, https://www.defense.gov/Portals/1/Documents/pubs/2018-National-Defense-Strategy-Summary.pdf.

> experimentation should be used prior to defining requirements and commercial off-the-shelf systems.[45]

Under Secretary Griffin reiterated the need for DOD to pursue new approaches to innovation in testimony before the House Armed Services Committee. "We are and must remain open-minded to new ways of executing missions," said Griffin, later adding

> Identifying [commercial] centers of excellence to spearhead investment portfolios is a way to maximize our agility in innovation and to pursue diverse investment strategies. Several of the Department's initiatives (i.e., the Army Research Lab Open Campus, the Defense Innovation Unit-Experimental (DIUx), and the pilot program with In-Q-Tel) are expanding avenues to grow Department and industry partnerships. Beyond technical innovation, the Department continues to pursue new practices and organizational structures to support a culture of innovation.[46]

Two of the initiatives identified by Under Secretary Griffin—the Army Research Lab Open Campus and DIU—are discussed in greater detail later in this report.

Selected Congressional and Executive Branch Actions

Over the past several years, policymakers and others have expressed concern that the long-held technological edge of the U.S. military is eroding. This erosion is attributed, in part, to the increased development of advanced technologies outside the defense sector and to DOD organizational and cultural barriers to effectively incorporating and exploiting commercial innovations. Some have also expressed concerns about the extent and effectiveness of DOD's engagement with leading-edge companies that have not historically been a part of the DOD innovation ecosystem. Congress has taken a number of actions to address these concerns, some of which are described below; the actions described should be consider illustrative and not exhaustive.

Reorganizing to Foster Innovation: Reestablishing the Position of Under Secretary of Defense for Research and Engineering

In 2016, through the National Defense Authorization Act for Fiscal Year 2017 (FY2017 NDAA, P.L. 114-328), Congress eliminated the position of the Under Secretary of Defense for Acquisition, Technology, and Logistics (USD (AT&L)) and established the positions of Under Secretary of Defense for Research and Engineering (USD (R&E)) and Under Secretary of Defense for Acquisition and Sustainment (USD (A&S)).

The establishment of the USD (R&E) as the fourth highest ranking DOD official—below only the Secretary, Deputy Secretary, and Chief Management Officer—was intended to promote faster innovation and to reduce risk-intolerance in the pursuit of new technologies.[47] In general, the

[45] Ibid., pp. 10-11.

[46] Testimony of Under Secretary of Defense for Research and Engineering Mike Griffin before the House Committee on Armed Services, hearing on "Promoting DOD's Culture of Innovation," April 18, 2018, https://www.armed-services.senate.gov/download/griffin_04-18-18.

[47] P.L. 114-328 established the position of USD (R&E) and gave it precedence behind the Secretary and Deputy Secretary of Defense. Subsequently, P.L. 115-91 established the position of Chief Management Officer and gave it precedence behind the Secretary and Deputy Secretary of Defense and above the USD (R&E), making USD (R&E) fourth in DOD precedence.

position of USD (R&E) was created as a response to the perception that the "acquisitions culture" dominated the office of the USD (AT&L), discouraging innovation and experimentation by the research and engineering staff and was not in alignment with the "fail fast" mentality of the broader innovation community.

Over the course of DOD's history, leadership for research, engineering, and technology development has existed at various levels within the Office of the Secretary of Defense (OSD), including an Assistant Secretary of Defense for Research and Engineering and a Director of Defense for Research and Engineering. Prior to the reestablishment of the position of the USD (R&E) in the FY2017 NDAA, the position of USD (R&E) was in place from 1977 to 1986.

In reestablishing the position of USD (R&E), the Senate Committee on Armed Services stated (S.Rept. 114-255)

> The committee expects that just as previous USD(R&E) incumbents led the so-called "Second Offset" strategy, which successfully enabled the United States to leap ahead of the Soviet Union in terms of military technology, the new USD(R&E) would be tasked with driving the key technologies that must encompass what defense leaders are now calling a "Third Offset" strategy: cyber and space capabilities, unmanned systems, directed energy, undersea warfare, hypersonics, and robotics, among others.

A key factor driving the establishment of the USD (R&E) and giving it precedence above the USD (A&S) was concern that DOD technology development had become too risk averse under the acquisition-dominant culture of AT&L. In the conference report (H.Rept. 114-840) for the FY2017 NDAA, the conferees stated their expectation that the USD (R&E) "would take risks, press the technology envelope, test and experiment, and have the latitude to fail, as appropriate."

P.L. 114-328 outlines the powers and duties of the USD (R&E) to include

- serving as the chief technology officer of DOD with the mission of advancing technology and innovation for the military services and DOD;
- establishing policies on, and supervising and coordinating, DOD's research and engineering, technology development, technology transition, prototyping, experimentation, and developmental testing activities and programs, including the allocation of resources for defense research and engineering; and
- serving as the principal advisor to the Secretary of Defense on all research, engineering, and technology development activities and programs in DOD.

On February 15, 2018, the Senate confirmed Michael D. Griffin as the first USD (R&E) under the new authority. It remains to be seen if the new organizational structure will be successful in achieving congressional intent and helping to create a more risk tolerant and innovative DOD.

In addition to creating the USD (R&E) and elevating its role in the DOD innovation process, as part of its reform efforts, Congress shifted certain acquisition authority and day-to-day management of RDT&E activities and programs back to the military services.[48] The extent to which this shift in authorities and responsibility will have an influence on the role and efficacy of the USD (R&E) remains to be seen. In response to a question about what authorities and responsibilities the USD (R&E) should have, Griffin stated

> I personally believe it was a very good idea to delegate programs back to the services to run on a day-to-day basis. [However, as a result,] the authorities that the USD (R&E) has

[48] For more information on acquisition reform see CRS Report R45068, *Acquisition Reform in the FY2016-FY2018 National Defense Authorization Acts (NDAAs)*, by Moshe Schwartz and Heidi M. Peters.

> do not include the ability to direct funding. They do not include the ability to direct programs or program direction. So, therefore, the office [of the USD (R&E)] is persuasive or advisory in nature.[49]

Congress may monitor how effectively the USD (R&E) is able to accomplish its mission in the absence of direct authority over programs and funding. In this regard, Congress may opt to examine the evolution of the relationship between the USD (R&E) and the military services.

Outreach to Companies Outside of the Traditional Defense Base: The Role of the Defense Innovation Unit (DIU)

In 2015, former Secretary of Defense Ash Carter created the Defense Innovation Unit[50] (DIU) to address the concern that DOD was not adequately engaged with start-up technology companies and other commercial enterprises generating innovative technologies. In announcing DIU, Secretary Carter indicated that the organization's mission was to "strengthen existing relationships and build new ones; help scout for new technologies; and help function as a local interface" between Silicon Valley and DOD.[51]

In 2016, DIU was expanded to include offices in the technology hubs of Boston, MA, and Austin, TX, and restructured to reflect a partnership-style leadership model common in venture capital firms. In 2018, DIU added an office in Washington, DC. According to DIU, it is "a fast-moving government entity that provides nondilutive capital to companies to solve national defense problems." In general, DIU uses other transaction authority to acquire prototypes from nontraditional defense contractors; other transactions are not subject to federal acquisition regulations and are viewed as providing federal agencies with more flexibility than traditional acquisition mechanisms, such as grants, contracts, or cooperative agreements.[52] For further discussion of this issue, see "Expanding Flexibility: Other Transaction Authority" below.

DIU has continued under the Trump Administration, with Defense Secretary James Mattis stating that "there is no doubt in my mind that DIUx will not only continue to exist, it will actually, it will grow in its influence and its impact on the Department of Defense."[53]

Some Members of Congress have been more measured in their support for DIU and its ability to engage new and nontraditional commercial sources of innovation.[54] The conference report to the FY2017 NDAA (H.Rept. 114-840) stated

> The conferees remain cautiously optimistic that the changes to the organizational structure and functions of DIUx could become important tools for the Department of Defense (DOD) to engage with new and non-traditional commercial sources of innovation, as well as

[49] U.S. Congress, Senate Committee on Armed Services, Subcommittee on Emerging Threats and Capabilities, *Accelerating New Technologies to Meet Emerging Threats*, 115th Cong., 2nd sess., April 18, 2018.

[50] The Defense Innovation Unit was formerly called the Defense Innovation Unit Experimental or DIUx.

[51] Remarks of Secretary of Defense Ash Carter, at Stanford University, "Rewiring the Pentagon: Charting a New Path on Innovation and Cybersecurity," press release, April 23, 2015, https://www.defense.gov/News/Speeches/Speech-View/Article/606666/drell-lecture-rewiring-the-pentagon-charting-a-new-path-on-innovation-and-cyber/.

[52] U.S. Government Accountability Office, *Military Acquisitions: DOD Taking Steps to Address Challenges Faced by Certain Companies*, GAO-17-644, July 20, 2017, p. 27.

[53] Department of Defense, "Media Availability with Secretary Mattis at DIUx," transcript, August 10, 2017, https://www.defense.gov/News/Transcripts/Transcript-View/Article/1275373/media-availability-with-secretary-mattis-at-diux/.

[54] Philip Marcelo, "Mattis, Hill Republicans Clash over Potential Diux Future," *Defense News*, August 11, 2017.

> rapidly identify and integrate new technologies into defense systems. The conferees believe that outreach to commercial companies, small businesses and other non-traditional defense contractors, in Silicon Valley and across the nation, will be a key element in all efforts at modernizing defense systems and pursuing offsetting technology strategies. However, the conferees are concerned that investments made by DIUx to-date were not focused on rapid delivery of much needed game-changing technologies… Additionally, the conferees remain concerned that in the Department's rush to try something new, defense leaders have not taken the time to determine how effective recent organizational and management changes are before seeking a rapid expansion of resources. Nor do the conferees believe that the Department has postured DIUx to be successful in the innovation ecosystem with partners across the Department, finding ways to multiply the effectiveness and networking potential of DIUx by leveraging the personnel, expertise, authorities, and resources of existing successful research, development, innovation, and tech transfer mechanisms.[55]

More recently, in the Department of Defense and Labor, Health and Human Services, and Education Appropriations Act, 2019 and Continuing Appropriations Act, 2019 (P.L. 115-245), Congress provided DIU with $44 million in funding, a level more than $27 million below the President's budget request of $71.1 million. The reason provided for the reduced level was unjustified mission and personnel growth.[56] Additionally, the John S. McCain National Defense Authorization Act for Fiscal Year 2019 (P.L. 115-232), requires the USD (R&E) to submit a report to Congress detailing how DIU will be integrated into the broader DOD research and engineering community, how the impact and effectiveness of the agency will be measured, and how DOD is institutionalizing best practices to alleviate systematic problems with technology access. In total, congressional actions point to the following questions:

- How can DIU serve as an effective 'change agent' within the department—helping to foster a broad based cultural shift and not become just another isolated workaround?
- How can DIU address the challenges that prevent nontraditional companies from doing business with DOD (e.g., the complexity of DOD's process and long contracting timelines)?
- What is the appropriate size and level of funding for DIU?
- What technical areas should DIU be focused on?
- How does DIU determine the scale and scope of its investment in a given area?
- Is the DIU model effective at rapidly identifying and integrating new technologies into defense systems?

Increasing Collaboration with Academia and Industry

In addition to DIU, DOD has been pursuing other means of increasing collaboration and interaction with academia and industry. The following sections provide a few illustrative examples. Additionally, the box items, "Artificial Intelligence: DOD and Google: Are There Social and Ethical Barriers to Engaging with U.S. Technology Companies?" and "Computer Chips: Too Costly for Commercial Chipmakers to Meet DOD Needs?," illustrate the

[55] U.S. Congress, House Committee on Armed Services, *National Defense Authorization Act for Fiscal Year 2017*, conference report to accompany S. 2943, 114th Cong., 2nd sess., November 30, 2016, H.Rept. 114-840, p. 992.

[56] U.S. Congress, House Committee on Appropriations, *Department of Defense for the Fiscal Year Ending September 30, 2019, and for Other Purposes*, conference report to accompany H.R. 6157, 115th Cong., 2nd sess., September 13, 2018, H. Rept, 115-952, pp. 473, 227.

types of potential challenges DOD may face in expanding its engagement with leading U.S. technology companies.

Defense Innovation Board

The Defense Innovation Board (DIB) was established in 2016 by the Department of Defense as an independent federal advisory committee. DIB members are appointed by the Secretary of Defense. Among its members are senior representatives from leading U.S. technology companies, venture capital firms, research institutes, and universities (including schools of business and technology). The DIB provides advice to the Secretary of Defense and other senior leaders across DOD with "independent advice and recommendations on innovative means to address future challenges through the prism of three focus areas: people and culture, technology and capabilities, and practices and operations." Efforts to date have focused on artificial intelligence and machine learning; software workforce capacity building; hiring and retention of innovation, science, technology, engineering, and mathematics (I+STEM) talent; acquisition reform; communication networks; information technology infrastructure; and working with the technology industry.[57]

Congress may conduct oversight of DOD implementation of DIB recommendations. Additionally, Congress may opt to leverage the expertise of DIB members regarding potential policy changes and other reform efforts that Congress might consider to ensure the innovative capacity of DOD is sustained over the long-term.

Army: Open Campus Initiative and Army Venture Capital Initiative

The Army Research Laboratory describes its Open Campus Initiative as "an effort to create strong, enduring S&T partnerships" through the co-location of Army R&D personnel in S&T hubs.[58] Congress has been broadly supportive of these efforts and has encouraged DOD to expand its presence both locally and globally. For example, in P.L. 115-232, Congress cited the open campus program as a model for other DOD laboratories to increase and improve their collaboration with the larger research and engineering enterprise. Specifically, the House Appropriations Committee conference report on the legislation (H.Rept. 115-676) stated

> The committee recommends that the Department better enable laboratories and centers to embrace an open and innovative posture, while simultaneously becoming more active in the Department's requirements process. The committee is aware of the Army Research Lab's Open Campus project as an example of open innovation that encourages groundbreaking advances in basic and applied research areas through increased collaboration with the broader research enterprise. The committee believes that this serves as a model for laboratories to become more ingrained in the scientific and research communities, both locally and globally, and become a greater sensor for disruptive technologies that present opportunities or highlight vulnerabilities for the Department. Additionally, the committee recommends that the laboratories increase their presence in innovation hubs across the United States.[59]

Congress has also been supportive of DOD-backed venture capital funds as a way to increase ties with start-ups and innovative companies, often citing the Central Intelligence Agency's nonprofit In-Q-Tel as a successful model. In 2002, through the defense appropriations act (P.L. 107-117), Congress set aside $25 million for the Secretary of the Army to establish a venture capital

57 Defense Innovation Board, https://innovation.defense.gov/.

58 U.S. Army, "Open Campus," at https://www.arl.army.mil/opencampus/.

59 U.S. Congress, House Committee on Appropriations, *National Defense Authorization Act for Fiscal Year 2019*, report to accompany H.R. 5515, 115th Cong., May 15, 2018, H.Rept. 115-676 (Washington: GPO, 2018), p. 72.

investment corporation. The resulting nonprofit corporation, the Army Venture Capital Initiative (AVCI), has been in existence since 2003; however, there is little information on the impact and success of the investments made by AVCI to date. Congress may opt to examine AVCI and other venture capital funds and investments made by DOD to ensure these resources are effective, being properly managed, and addressing congressional intent of serving as a bridge between DOD and innovative companies.

Artificial Intelligence: DOD and Google: Are There Social and Ethical Barriers to Engaging with U.S. Technology Companies?

Artificial intelligence (AI)—generally characterized as computerized systems that work and react in ways commonly thought to require intelligence, such as solving complex problems in real-world situations—is a prime example of a technology area where innovation is being driven largely by the private sector rather than the federal government.

The private sector is investing heavily in AI because of its potential for transforming existing industries and creating new ones. In the near term, AI offers the potential for substantial productivity gains by improving decision-making, automating processes, and substituting for human labor. For example, AI is fundamental to the deployment of autonomous vehicles; self-optimizing manufacturing processes; allowing for voice-based human-machine interfaces; and identifying, anticipating and responding to customer needs and preferences. In the longer term, AI and more powerful computing capabilities are expected to achieve, then surpass, the speed and complexity of the human brain, and to act on such "thoughts" nearly instantaneously. The implications of such technology, acting at the direction of human beings and/or acting autonomously, are enormous.

Similarly, AI offers the potential for near-term and long-term applications in national security. Potential adversaries such as Russia and China are investing heavily in AI's commercial and military applications. In this context, many consider capitalizing on AI essential to maintaining the superiority of the United States military. With advances in AI being driven primarily by the private sector, many believe DOD must find new mechanisms for engaging with companies that have not been part of the traditional defense industrial base. Thus, DOD is seeking to partner with leading U.S. technology companies in the development of AI applications for a wide range of military functions (e.g., intelligence collection and analysis, logistics, cyberspace operations).

However, recent developments in the partnership between DOD and Google highlight a potential concern that extends beyond the bureaucratic challenges DOD faces in engaging with nontraditional defense contractors. Earlier this year, Google announced that it would not renew its contract with DOD for the work it was doing on Project Maven—a program focused on adapting commercial AI algorithms to detect, classify, and track objects from drone surveillance to enhance military decision-making. Google's decision to terminate its relationship with DOD was sparked by a letter from more than 4,000 Google employees who objected to the company's involvement in the program. The letter stated, "recognizing Google's moral and ethical responsibility, and the threat to Google's reputation, we request that you: (1) cancel this project immediately; (2) draft, publicize, and enforce a clear policy stating that neither Google nor its contractors will ever build warfare technology."[60]

Google subsequently released a set of AI principles, stating that the principles are "concrete standards that will actively govern our research and product development and will impact our business decisions."[61] Concern over violating the company's AI principles was cited as one of the reasons Google recently decided to pull out of the competition for the Pentagon's Joint Enterprise Defense Infrastructure (JEDI) cloud computing and storage contract valued at more than $10 billion.[62]

Some experts believe other U.S. technology companies will step in to fill potential gaps created by Google's decision to end its partnership with DOD on Project Maven. However, the Google experience suggests DOD may face additional challenges in its efforts to engage with leading edge technology companies if their employees have social and ethical concerns regarding the use of their expertise in the development of military technologies.

For more information on AI and national security see CRS Report R45178, *Artificial Intelligence and National Security*, by Daniel S. Hoadley and Nathan J. Lucas.

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60 Daisuke Wakabayashi and Scott Shane, "Google Will Not Renew Pentagon Contract That Upset Employees," *New York Times*, June 1, 2018.

61 Sundar Pichai, CEO, "AI at Google: Our Principles," https://www.blog.google/technology/ai/ai-principles/.

62 Naomi Nix, "Google Drops Out of Pentagon's $10 Billion Cloud Competition," Bloomberg, October 8, 2018.

Computer Chips: Too Costly for Commercial Chipmakers to Meet DOD Needs?

The Department of Defense requires small-run and custom computer chips for a wide range of applications with unique security requirements due to departmental concerns about the potential for the chips to be compromised, including missiles, jet aircraft, and satellites. But the production of these chips comes with unique security requirements due to DOD concerns about the potential of the chips to be compromised.

Not only do DOD chips need to perform reliably under often harsh and extreme conditions, DOD must be certain that they haven't been compromised in any manner by potential adversaries or hackers. Compromised chips might allow an adversary to remotely activate a designed function (e.g., control navigation, detonate a bomb), to activate a function embedded by the enemy (e.g., covertly acquire and send data, open a "backdoor" to enable control of the system), or to make the chip nonfunctional. Such compromises may be extremely difficult to detect during chip testing. In addition, chip production outside of a secure facility could provide adversaries information on U.S. military capabilities or functionality, and lower the barrier to theft of critical technologies.

Whereas federal agencies—DOD and the National Aeronautics and Space Administration (NASA), in particular—were once large and vital customers of chips, this is no longer the case. Throughout the 1950s, DOD took efforts to increase the uptake of semiconductors. Following the development of the integrated circuit (IC) by Texas Instrument's Jack Kilby in 1958, the federal government played a major role in advancing the chip industry through R&D funding and acquisitions. In the early 1960s, federal government purchases (including guidance systems for the NASA Apollo program and the Minuteman-II missile[63]) accounted for an estimated 100% of U.S. IC production.[64] This market dependence made private producers highly responsive to government requirements. However, by 1970, the U.S. military's share of U.S. IC sales had fallen to around 20%, and by 1980 to below 10%.[65] By 2016, DOD systems and programs accounted for less than 1% of global semiconductor output.[66]

Also, production runs for DOD-unique chips are often small compared to chips produced for commercial applications, and leading-edge fabrication (fab) plants are expensive. For example, in May 2015 Samsung announced plans for a $14 billion fab plant and in 2017 the Taiwan Semiconductor Manufacturing Company announced plans for a $20 billion state-of-the-art plant.[67] (In contrast, fab plants established in the mid-2000s were estimated to cost $2 billion to $3 billion.) In addition, the useful life of a new fab plant is estimated at 5-7 years.[68] Such large investments and short useful lives require large-scale production to be profitable.

Small production runs, high performance requirements, and DOD's declining share of chip consumption has made it less attractive for chip producers to serve the DOD market. The opportunity to serve DOD may come at a price that private companies are unwilling to pay: operating small-run production facilities. Such an operation involves not only additional expenses, but comes with high opportunity costs—using the company's highly-trained scientists, engineers, technicians, and managers; capital; and state-of-the-art equipment that might otherwise be used for serving higher return commercial markets.

The House Armed Services Committee noted in H.Rept. 114-537 accompanying the National Defense Authorization Act for Fiscal Year 2017, "due to market trends, supply chain globalization, and manufacturing costs, the Department's future access to U.S.-based microelectronics sources is uncertain." Industry consolidation has led to DOD considering non-U.S. companies to meet its needs. Then-Deputy Assistant Secretary of Defense for Manufacturing and Industrial Base Policy Andre Gudger is quoted in a July 2016 *Wall Street Journal* article saying, "Our goal is to look globally. We want access to the latest and the greatest."

Air Force: Wright Brothers Institute and CyberWorx

The Air Force has initiated a number of partnerships to expand collaboration and to engage nontraditional partners. Examples include a partnership between the Air Force Research

[63] Anna Slomovic, *Anteing Up: The Government's Role in the Microelectronics Industry,* December 1988, p. 6, http://www.dtic.mil/dtic/tr/fulltext/u2/a228267.pdf.

[64] The Brookings Institution, *International Diffusion of Technology: The Case of Semiconductors,* John E. Tilton, 1971.

[65] David C. Mowery, Haas School of Business, University of California at Berkeley, "Federal Policy and the Development of Semiconductors, Computer Hardware, and Computer Software: A Policy Model for Climate Change R&D?," in *Accelerating Energy Innovation: Insights from Multiple Sectors* (National Bureau of Economic Research, 2011), p. 25, http://www.nber.org/chapters/c11753.pdf.

[66] Daniel J. Radack, et al., Institute for Defense Analysis, *Semiconductor Industrial Base: Focus Study–Final Report*, September 2016, p. i, https://www.ida.org//idamedia/Corporate/Files/Publications/IDA_Documents/ITSD/2017/D-

Laboratory and the Wright Brothers Institute (WBI) to provide collaborative environments for industry, academia, and government to accelerate development and commercialization in aerospace, advanced materials and manufacturing, human performance, sensors, and environmental technologies; and a partnership between the U.S. Air Force Academy (USAFA) and the nonprofit Center for Technology, Research and Commercialization to establish CyberWorx to accelerate the delivery of capabilities to the warfighter through human-centered design, public partnering, rapid prototyping, and testing by bringing together USAFA cadets, experienced operational airmen, and industry.

Navy: Wright Brothers Institute

The Navy has established such partnerships as well. For example, the Naval Surface Warfare Center, Crane Division, signed a partnership intermediary agreement with WBI to align "complimentary technologies, sourcing commercial markets, connecting technical experts, and engaging manufacturers to further commercialization."

U.S. Special Operations Command: SOFWERX

The U.S. Special Operations Command (USSOCOM) has established a partnership intermediary agreement with the nonprofit Doolittle Institute to implement SOFWERX, an intermediary to assist with collaboration, innovation, prototyping, rapid proof of concepts, and exploration among industry, government laboratories, and academic partners.

Expanding Flexibility: Other Transaction Authority

Over the years, Congress has expanded DOD's authority to use other transactions (OTs). OT agreements do not have to comply with federal procurement regulations and are generally viewed as giving federal agencies additional flexibility, including the ability to develop agreements that are specifically tailored to the needs of the project and its participants. There is no statutory or regulatory definition for OTs. Instead, OTs are a more flexible alternative to contracts, grants, and cooperative agreements. OTs are legally binding agreements that are generally exempt from most federal procurement laws and regulations, such as the Federal Acquisition Regulation and the Competition in Contracting Act.[69] In contrast, traditional procurement contracts must adhere to the procurement-specific requirements set forth in statute and regulation. OTs, however, are bound by standard contract and other select laws and regulations, such as the Anti-Deficiency Act and the Trade Secrets Act.[70] Only those agencies that have been provided OT authority may engage in other transactions.[71]

8294.pdf.

[67] R. Colin Johnson, "Samsung Breaks Ground on $14 Billion Fab," EE Times, May 8, 2015, http://www.eetimes.com/document.asp?doc_id=1326565; Samson Ellis, Yuan Gao, Cindy Wang "TSMC Ready to Spend $20 Billion on its Most Advanced Chip Plant," Bloomberg, October 6, 2017, https://www.bloomberg.com/ news/articles/2017-10-06/tsmc-ready-to-spend-20-billion-on-its-most-advanced-chip-plant.

[68] Institute for Defense Analysis, *Semiconductor Industrial Base: Focus Study–Final Report*, September 2016, pp. 4-1.

[69] Defense Procurement and Acquisition Policy, Other Transaction Guide for Prototype Projects, Version 1.2.0, 2017, p. i; Kenneth Patton, "GAO Says Oracle Protest Did Not Make Policy; Criticizes Greenwalt Op-ed," Breaking Defense, July 9, 2018, https://breakingdefense.com/2018/07/gao-says-oracle-protest-did-not-make-policy-criticizes-greenwalt-op-ed/.

[70] Defense Procurement and Acquisition Policy, Other Transaction Guide for Prototype Projects, Version 1.2.0, 2017.

[71] For more information on other transactions see U.S. Government Accountability Office, *Federal Acquisitions: Use of*

Congress provided the Defense Advanced Research Projects Agency (DARPA) with OT authority in 1989.[72] DARPA is often cited by Congress and others when discussing how to improve the ability of the federal government to spur innovation through its R&D investments. DARPA officials contend that its organizational structure allows the agency to operate in a fashion that is unique within DOD, as well as the entire federal government. Specifically, DARPA officials assert that the agency's relatively small size and flat structure enable flexibility and allow the agency to avoid internal processes and rules that slow action in other federal agencies.[73]

In the National Defense Authorization Act for Fiscal Year 2016 (P.L. 114-92), Congress made permanent DOD's ability to use OTs for acquiring prototypes and extended the use of OTs to follow-on production activities.[74] In making these changes, the joint explanatory statement to P.L. 114-92 stated

> We believe that the flexibility of the OTA authorities of section 2371 of title 10, United States Code, and the related and dependent authorities of section 845 of the National Defense Authorization Act for Fiscal Year 1994 (Public Law 103–160) as modified and codified in this provision, can make them attractive to firms and organizations that do not usually participate in government contracting due to the typical overhead burden and "one size fits all" rules. We believe that expanded use of OTAs will support Department of Defense efforts to access new source[s] of technical innovation, such as Silicon Valley startup companies and small commercial firms.[75]

On February 1, 2018, DIU used its OT authority to award a follow-on production contract to REAN Cloud for $950 million. The issuance of the follow-on production contract raised some concerns from potential competitors and resulted in Oracle America, Inc., filing a bid protest with the U.S. Government Accountability Office (GAO) that was sustained by GAO on May 31, 2018.[76] According to media reports, senior Pentagon officials "were not aware of the production agreement prior to it being announced."[77] In an effort to gain more insight into the use of OTs, the National Defense Authorization Act for Fiscal Year 2019 (P.L. 115-232) includes language that requires DOD to collect data on the use of OTs and to submit a report to Congress each year summarizing the purpose, description, and status of each OT agreement entered into by DOD, including the organizations involved and the size of the contract. In conjunction with the House version of the provision, the House Armed Services Committee stated

'Other Transaction' Agreements Limited and Mostly for Research and Development Activities, GAO-16-209, January 7, 2016.

[72] For more information about DARPA see CRS Report R45088, *Defense Advanced Research Projects Agency: Overview and Issues for Congress*, by Marcy E. Gallo.

[73] Defense Advanced Research Projects Agency, "Innovation at DARPA," July 2016, pp. 22-23, at http://www.darpa.mil/attachments/DARPA_Innovation_2016.pdf.

[74] In 1993, through P.L. 103-160, Congress provided the Director of the Defense Advanced Research Projects Agency with the authority to use OTs for prototypes; this authority was expanded to include the Secretary of a military department or any other official designated by the Secretary of Defense in 1996 through P.L. 104-201.

[75] U.S. Congress, House Committee on Armed Services, *National Defense Authorization Act for Fiscal Year 2016*, committee print, Legislative Text and Joint Explanatory Statement to accompany S. 1356, P.L. 114-92, 114th Cong., 1st sess., November 2015, pp. 700-701.

[76] U.S. Government Accountability Office, *Oracle America, Inc.*, B-416061, May 31, 2018, https://www.gao.gov/products/D19096.

[77] Anthony Capaccio, "Pentagon Says It Was Caught Off-Guard by $950 Million Cloud Deal," *Bloomberg News*, March 6, 2018, https://www.bloomberg.com/news/articles/2018-03-06/pentagon-says-it-was-caught-off-guard-by-950-million-cloud-deal.

> The committee remains committed to providing the Department of Defense the needed flexibility to acquire advanced capabilities through streamlined and expedited processes. The committee recognizes that other transaction authority has been an effective tool for research and development, particularly for execution of science, technology, and prototyping programs. It provides needed flexibility in terms of adherence to select Federal acquisition regulations. While the benefits of this flexibility are clear, the committee believes that it is still necessary to exercise effective oversight both to understand the ways in which the Department is properly leveraging the use of this authority and to prevent its abuse or misuse.[78]

Congress may opt to provide oversight as DOD increases its use of OTs to ensure that it does so in a way that is consistent with congressional intent, including increasing the number of nontraditional defense contractors and accelerating the transition of innovative technologies to the warfighter while effectively preventing potential waste, fraud, and abuse.

Potential Issues for Consideration

Research and development is now a global enterprise, with the private sector driving technology development. Some assert that DOD has been slow to react and adapt to this new reality, raising concerns that the United States military may be unable to maintain its historical technological advantages. Congress and the Administration have adopted a number of reforms to address the perceived concerns, including those described above. Many of these efforts will likely require sustained focus to ensure DOD transforms into a more innovative, risk-tolerant R&D organization that delivers new technologies to the warfighter in a timely and relevant manner. As Congress considers the impact of these reforms and their effectiveness, including the establishment of the position of USD (R&E), there are a number of questions it may want to consider.

In the near-term, Congress may want to focus its oversight efforts on organizational, structural, and procedural changes, especially those implemented by the USD R&E, who is tasked with leadership of DOD's R&D enterprise. For example, policymakers may want to consider

- How is the office of the USD (R&E) structured? How does the organizational structure compare to the prior version of the office of USD (R&E) and is it effective?
- What level of staffing and technical expertise is appropriate for the office of the USD (R&E) to meet its goals and mission?
- Has the USD (R&E) created an overarching vision and strategic plan for DOD's research, development, testing, and evaluation (RDT&E) activities and programs? Has the USD (R&E) sought and incorporated the perspectives of various stakeholders, including industry, academia, and DOD services and agencies in the development of an RDT&E strategic plan?
- If there is an RDT&E strategic plan, what steps have been taken to implement the plan? How does the plan prioritize RDT&E activities and investments? How does it ensure DOD maintains an adequate technical workforce? How does it ensure DOD's R&D facilities and test infrastructure are state-of-the-art and adequately maintained?

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[78] U.S. Congress, House Committee on Armed Services, *National Defense Authorization Act for Fiscal Year 2019*, report to accompany H.R. 5515, 115th Cong., May 15, 2018, H.Rept. 115-676 (Washington: GPO, 2018), p. 162.

- What policies and processes has the USD (R&E) put in place to ensure adequate and appropriate coordination of RDT&E programs and activities among and between DOD RDT&E organizations and those of the military branches?
- How do these policies and processes differ from previous coordination-related efforts?
- What, if any, best practices from previous iterations of the USD (R&E) have been reestablished under the current USD (R&E)?
- What, if any, policies or procedures has the USD (R&E) implemented to help foster a culture of risk-taking and an appropriate tolerance for failure within DOD?
- What, if any, policies or procedures has the USD (R&E) implemented to increase DOD collaboration and engagement with leading-edge technology companies that have not historically been a part of DOD's innovation ecosystem? What barriers and challenges has DOD found with respect to such expanded collaboration and engagement?

In the mid-term and long-term, Congress may want to focus its oversight efforts on outcomes of congressional and DOD actions. For example:

- How are promising technologies being transitioned into operational use and what are the appropriate metrics for determining success?
- Has DOD increased the use of prototypes and other experimentation methods? What has DOD learned from the greater use of prototypes and other methods?
- Has DOD increased its tolerance for failure? How has the failure rate and failure speed of projects changed? How quickly are resources redeployed to new potential opportunities? For example, is DOD pursuing multiple lines of inquiry simultaneously with some projects failing and resources being quickly reallocated accordingly?
- Is the USD (R&E) effectively leveraging and coordinating RDT&E activities and investments across DOD and with other federal agencies?
- Is the DOD RDT&E strategic plan being effectively implemented? Is DOD addressing and advancing identified technological goals and needs in areas deemed critical for the future military (e.g., artificial intelligence, hypersonics, directed energy)?
- Has DOD increased collaboration and partnership with leading-edge technology companies that have not historically been a part of DOD's innovation ecosystem?
- Is DOD effectively using other transaction authority to increase its innovative capacity and access technologies outside of the agency's traditional contractor base?
- Is DOD using special hiring authorities appropriately and effectively in recruiting and retaining outstanding scientific and engineering talent?
- How systemic are the changes in the DOD culture of innovation? What signs of change and innovation are being observed in core elements of DOD outside of special offices such as the Defense Innovation Unit (DIU), the Strategic Capabilities Office (SCO), or the rapid capabilities offices within the military services?

As the global R&D landscape continues to evolve, Congress may conduct hearings to stay apprised of the competitive positions of near-peer nations (and firms) in key fields of science and technology; the science, technology, and innovation policies of those countries; and new and emerging models for technology development and innovation.

Appendix. Selected Science, Technology, and Innovation Laws Enacted in the 1980s

Stevenson-Wydler Technology Innovation Act of 1980 (P.L. 96-480)

The Stevenson-Wydler Technology Innovation Act of 1980 articulated a clear and strong linkage between U.S. economic performance and technological leadership, stating "technology and industrial innovation are central to the economic, environmental, and social well-being of citizens of the United States.... Increased industrial and technological innovation would reduce trade deficits, stabilize the dollar, increase productivity gains, increase employment, and stabilize prices."[79]

The act expressed concern about potential U.S. decline, noting that "Industrial and technological innovation in the United States may be lagging when compared to historical patterns and other industrialized nations." Further, the act asserted the need for a comprehensive national policy to enhance technological innovation for commercial and public purposes, including a strong national policy supporting domestic technology transfer and utilization of the science and technology resources of the Federal Government.

Among its provisions, the act sought to improve technology transfer from federal laboratories to industry by requiring federal laboratories to take an active role in technical cooperation, expanding the dissemination of information about research activities and results, and establishing Offices of Research and Technology Applications at major federal laboratories to coordinate and promote technology transfer. The act also established an Office of Industrial Technology at the Commerce Department with a broad mandate to conduct and report studies and policy experiments related to technology, innovation, and industrial and national economic performance.

Government Patent Policy Act (P.L. 96-517, referred to as the "Bayh-Dole Act")

The Government Patent Policy Act (P.L. 96-517, commonly referred to as the "Bayh-Dole Act") provided small businesses, universities, and not-for-profit organizations the right to obtain titles to inventions developed with federal funds. President Ronald Reagan issued a memorandum in 1983 and Executive Order 12591 in 1987 directing federal agencies to apply this provision to all businesses, regardless of size, to the extent permitted by law.

Small Business Innovation Development Act of 1982 (P.L. 97-219)

The Small Business Innovation Development Act of 1982 (P.L. 97-219) established the Small Business Innovation Research program by requiring certain agencies to set aside a portion of their annual extramural R&D funding to competitively award R&D funds for small businesses.

Cooperative Research and Development Act of 1984 (P.L. 98-462)

The Cooperative Research and Development Act of 1984 (P.L. 98-462) sought to encourage firms to pool their research funds and engage in precompetitive research by eliminating treble damages for antitrust violations. The act contributed to the development of research consortia such as the Semiconductor Research Corporation (SEMATECH).

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[79] P.L. 96-480, Section 2.

Federal Technology Transfer Act of 1986 (P.L. 99-502)

The Federal Technology Transfer Act of 1986 (P.L. 99-502) authorized government-owned, government-operated (GOGO) laboratories to enter into cooperative research and development agreements (CRADAs) and to negotiate licenses on patents owned by the laboratories. It also required laboratories to share a portion of patent licensing royalties with the government employed inventor(s). The act made technology transfer, consistent with mission responsibilities, a responsibility of each laboratory scientist and engineer. In addition, the act codified the Federal Laboratory Consortium (FLC) and charged it with facilitating technology transfer through professional development training, providing advice and assistance to agencies and laboratories, and acting as a clearinghouse for requests for technical assistance received by laboratories.

Malcolm Baldrige National Quality Improvement Act of 1987 (P.L. 100-107)

The Malcolm Baldrige National Quality Improvement Act of 1987 (P.L. 100-107) sought to improve the quality of American goods and services by instituting an awards program to honor companies and other organizations that practice effective quality management, and by disseminating information about successful quality improvement strategies and programs. During this period, Japanese products were often seen as superior in quality to similar American products. During its recovery from WWII, Japan embraced the work of W. Edwards Deming, a leading pioneer in the field of statistical quality control (SQC) and total quality management (TQM), including industrial adoption of statistical process controls.

Omnibus Trade and Competitiveness Act of 1988 (P.L. 100-418)

The Omnibus Trade and Competitiveness Act of 1988 (P.L. 100-418), among other things:

- sought to facilitate more open, equitable, and reciprocal market access; reduce or eliminate barriers and other trade-distorting policies and practices; enable a more effective system of international trading disciplines and procedures; increase intellectual property protections; and improve enforcement of U.S. antidumping and countervailing duties;
- authorized trade adjustment assistance to firms and workers;
- extended federal patent royalty payments to nongovernment employees;
- declared as U.S. policy that federally supported international science and technology agreements should be negotiated to ensure that intellectual property rights are properly protected and that access to R&D opportunities and facilities, and the flow of scientific and technological information, are, to the maximum extent practicable, equitable and reciprocal;
- changed the name of the National Bureau of Standards to the National Institute of Standards and Technology (NIST), expanded its technology transfer role, and mandated an annual report on emerging technologies;
- established the NIST Advanced Technology Program (ATP) to assist U.S. businesses in creating and applying generic technology and research results needed to commercialize significant new scientific discoveries and technologies rapidly and to refine manufacturing technologies;
- established the NIST Manufacturing Extension Partnership (MEP) program to assist in the establishment of regional centers to enhance productivity and technological performance of U.S. small and medium-size manufacturers.

National Institute of Standards and Technology Authorization Act for 1989 (P.L. 100-519)

The National Institute of Standards and Technology Authorization Act for 1989 (P.L. (100-519), among other things, established a Department of Commerce Technology Administration, led by an Under Secretary for Technology, composed of NIST, the Office of Technology Policy, and the National Technical Information Service;

National Competitiveness Technology Transfer Act of 1989 (P.L. 101-189)

The National Competitiveness Technology Transfer Act of 1989 (P.L. 101-189) extended to government-owned, contractor-operated (GOCO) laboratories many of the same CRADA authorities provided to GOGOs by P.L. 99-502); protected information created under a CRADA from disclosure to third parties, and provided a technology transfer mission to the Department of Energy's nuclear weapons laboratories.

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