How DARPA has organized itself for innovation bears lessons for the U.S. economy that are more useful than the innovations themselves.

All That DARPA Can Be

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As World War II proceeded toward its second year and the U.S. production machine began to ship "Lend-Lease" war supplies to Britain, an enduring transfer was occurring in the opposite direction. In August 1940, British science leader Henry Tizard landed in Halifax and took a train to Washington, leading a small scientific team on a multi-month mission. In a suitcase they carried perhaps the most critical technology of the war: an early prototype of the microwave radar.

As important as the technology was, the innovation organization model that produced it turned out to be more important still. An American team led by industrial organizer and technologist Alfred Loomis and reporting to Vannevar Bush, FDR's science czar, not only replicated the technology but also grasped—first at MIT's Rad Lab and later at Los Alamos—the organizational lessons: form critical innovation institutions; organize them on an "island/bridge" model; create a thinking community; and link technologists to operators.

Thirteen years after the end of the war, these lessons were translated directly into the Defense Advanced Research Projects Agency (DARPA), perhaps the most successful Federal R&D agency in U.S. history. DARPA's achievements are legendary, but not as well understood as they might be. DARPA's fame rests in its having innovated in "frontier" technology sectors like information. But its greatest importance, in the past and prospectively, may lie instead in its bringing innovation to a certain "legacy" sector: the U.S. military bureaucracy.[1]

The Defense Department is once again poised at the technological brink: Its last major technological thrust in the 1980s and 1990s, which led to precision weapons, drones, and stealth, is rapidly being replicated by potential competitor nations. Its senior leadership recently announced that it seeks a new generation of "technology offsets" to keep the U.S.

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[1]See William B. Bonvillian and Charles Weiss, *Technological Innovation in Legacy Sectors* (Oxford 2015), pp. 119–34.

edge.[2] Within the five-sided fortress, needed new technologies are bound to face resistance, so a first-rate innovation organization model is essential to preserving U.S. military-technical superiority.

This kind of innovation—in human social software as opposed to mere machines—is bound to be more difficult. Launching it will be contested by vested interests appealing to arguments from authority. Legacy sectors constitute most of the U.S. economy, as it happens, cluttering the landscape of innovation in energy, medicine, education, transportation, manufacturing, and agriculture with entropy. If we can clone the DARPA organizational genius, and the system of innovation actors it is part of, to transform the U.S. military bureaucracy, that might lead the way toward transforming a great deal more.[3]

To put DARPA in perspective, we need to lay out briefly the five models for how innovation is organized in the United States. The most familiar model, evolved in the immediate postwar era, is the *pipeline*, or linear, model, developed by Vannevar Bush. Basic government-sponsored research operating at the frontiers of knowledge, largely in partnership with major research universities, leads to applied research and development, which in turn leads to invention, prototyping, and finally innovation and corresponding broad commercialization or deployment. While this process wasn't really linear (technology influenced science as well as the other way around), "pipeline" is still the term associated with this technology-push approach. It is a model where government provides a major initial input through basic research funding, but has a very limited role thereafter, and so constitutes an inherently disconnected model, with researchers separated from industry implementers.

The second model is that of *induced innovation* explored by economist Vernon Ruttan. Here technological innovation responds to changes in the market, generally to market niche opportunities and price signals. It is typically industry led. New products often arise through modifications of existing technologies to meet new market needs. It is a "technology pull" model, in which incremental advances occur far more often than major breakthroughs emerging from basic research.

The third model, a variation of the first, can be called the *extended pipeline*. In this model, government, in the form of the U.S. Defense Department, funds both the early stages of research and follow-on stages: development, prototyping, product design, demonstration, testing, and implementation. It also serves as the initial market. The internet, for example, came about this way, as did various aspects of innovation in aviation, electronics, space, nuclear power, and computing—in other words, most of the major technology innovation domains of the late 20th century. The spread from Defense Department auspices to the market was facilitated by the fact that many corporations (in the aerospace or early computing industries, for example) participated in both national defense and other sectors. In recent decades this model has migrated from defense to commercial space services, among others. At the same time, Federal R&D expenditures have lagged, or this migration might have expanded still further.

The fourth model, *manufacturing-led* innovation, describes innovations in both production processes and technologies that emerge from experience and expertise in manufacturing, typically augmented by R&D closely integrated with the production process. Production, particularly the initial production stage, can be highly innovative; this is where product design is completed and a new technological advance is reworked and rethought until it becomes a product that can be made at scale and meet a market need. It involves extensive and creative engineering; the original innovation and the scientific and technological learning behind it is often completely reworked. Japan's economic success through the creation of a quality manufacturing system in the 1970s and 1980s

[2] Charles Hagel, *The Defense Innovation Initiative*, Department of Defense, November 15, 2014; Frank Kendall, *Long Range Research and Development Plan (LRRDP) Direction and Tasking*, Department of Defense, October 29, 2014.

[3] See William B. Bonvillian and Richard Van Atta, "ARPA-E and DARPA: Applying the DARPA Model to Energy Innovation", *Journal of Technology Transfer* (October 2011).

demonstrated the importance of this stage.

These four models exist and already work with varying degrees of efficiency. The fifth model, the *innovation organization* model, is a conceptual framework that includes the other four and builds on them. Its essence is that innovation requires not only technology supply and a corresponding market demand, but also organizational elements that align and link the two. The focus in the science policy literature is on idea creation; detailed evaluation of implementation is largely ignored. This is a problem, especially in legacy domains of the economy. Frontier innovation need not confront a phalanx of inertia and habit; by definition, legacy innovation must. This means that to design and implement a successful innovation model, we must include the full innovation ecosystem in our thinking. That, in turn, requires including not just science and technology aspects but also culture and social structures, broadly defined.

The innovation organization model, then, moves beyond the institutional "linkage" idea of the extended pipeline model to embrace a series of elements that connect public and private sectors, from research through production. It merges aspects of pipeline and induced innovation, radical and incremental, and it seeks to overcome structural barriers to innovation, particularly relevant to legacy sectors, through change agents: institutional and individual actors whose purpose is to push innovation through the sector barriers at each innovation stage.

With this we come back to DARPA: While it fits historically with the "extended pipeline" model, it has also developed features that have enabled it to innovate in the legacy defense sector. The emerging outline of an overall "innovation organization" model will be crucial as the Office of the Secretary, DARPA, and their allies embark on a new innovation strategy for "technology offsets." This new task will illustrate key features of the innovation organization model—just what we need to reduce entropy in all our legacy economic sectors, not just defense, and increase synergy, creativity, and productivity.

There is an obvious rule functioning here: no innovations, no innovation system. Innovation entrepreneurs require not only an understanding of the overall system for its development; innovation also requires genuine new ideas with some sort of practical application. The "front end" of the innovation system is thus a necessary but not a sufficient element of innovation success and, ironically perhaps, it is a harder necessary element to bring about in legacy sectors than in out-of-the-blue frontier innovation. It means, in particular, that we must find ways to move beyond the "valley-of-death" stage between research and late-stage development—so-called because it is the place where many efforts go to die.

Consider, for example, the F-35 program. The prototypes developed at the Lockheed-Martin Skunk Works involved at least two significant innovations: qualitatively enhanced low-observable technology, and dramatic information science adaptations to a range of functions. The research stage went well, and the late-stage development of the entire platform has come around—but the middle stages were excruciating, in part because that required connecting the machines to the people who needed to be able to use them (both individual pilots and larger ensembles of operators). Innovation requires *connected* science and technology—linkages between innovation stages and the actors engaged with them. We must combine aspects of pipeline, induced, and the other innovation models into what Avery Sen and others call *transformative innovation.*

This transformational task of innovation for both frontier and legacy sectors will always depend on the front end of an innovation system—by definition for frontier sectors, but often enough for legacy sectors too. For example, in health care, incremental advances in electronic medical records could lead to dramatic improvements in efficiency (assuming we can figure out how to apply the data this will provide), but breakthrough medical devices and nano-scale drug delivery based on genomic assessments can also generate significant advances. Marrying different but simultaneously developing improvements puts a huge burden on the human organizational elements trying to apply the innovations. Similarly, in the energy sector, "smart" devices are evolving incrementally for the electric power grid, but breakthroughs in power electronics are needed, as well—and again, the organizational elements, complete with the regulatory and politics aspects they bring, represent an overarching challenge in part because there is no convening platform where all the organizational elements can plan together or transact business with each other as a unified function.

We know, thanks to DARPA and many people who have studied it, how to stimulate the front end. It requires four tasks.

1) Form critical innovation institutions. If R&D is not being conducted at an adequate scale by talented research teams, innovations will not emerge. But talent alone is not enough; talent must operate within institutional mechanisms capable of moving technology advances from idea to innovation. C*ritical innovation institutions* represent the space where research and talent combine, where the meeting between science and technology is best organized. Arguably, there are critical science and technology institutions that can introduce not simply inventions and applications, but significant elements of entire innovation systems.

This is where DARPA takes center stage, with its history of attracting outstanding research talent and of spurring remarkable technology advances. In promoting innovations, it has long played within both frontier sectors, through its role in the information technology wave, and the defense legacy sector, through its role in such defense advances as precision strike and unmanned aerial vehicles. As the most successful U.S. R&D agency operating in the innovation space, and because it represents more of a "connected science and technology" approach than other agencies, our initial focus is on lessons that can be learned from the characteristics of the DARPA model.

Formed in 1958 by President Eisenhower to provide more unified defense R&D in light of the separate, stove-piped military services' space programs that had helped lead to America's Sputnik failure, DARPA became a unique entity, aimed at both avoiding and creating "technology surprise."[4] In many ways, DARPA directly inherited the *connected science and technology* (linking science research to implementation stages) and *challenge* (pursuing major mission technology challenges) organization models of the Rad Lab and Los Alamos projects. Building on the Rad Lab example, DARPA built a deeply collaborative, flat, close-knit, talented, participatory, and flexible system, oriented to breakthrough radical innovation. Its challenge model for R&D moved between fundamental and applied, creating connected science and technology and linking research, development, and prototyping with access to initial production. In other words, it followed an innovation path, not simply a discovery or invention path.

However, innovation requires not only a process of creating connected science and challenges at the *institutional level*; it also must operate at the *personal level.* People, not simply the institutions where talent and R&D come together, are innovators. At the same time, because innovation is more complex than the earlier stages of discovery and invention, it requires "great groups", not simply individuals.[5] Unlike other Federal R&D agencies, DARPA has attempted to operate at *both* the institutional and personal levels. It became a bridge organization connecting these two institutional and personal organizational elements.

At the heart of the DARPA rule set is what Tamara Carleton has termed a "technology visioning" process, using a "right-left" research model: Its program managers contemplate the technology breakthroughs they wish to emerge from the right end of the innovation pipeline, then go back to the left side of the pipeline to look for proposals for the breakthrough research that will get them there.[6] As noted, it uses a challenge-based research model: seeking research advances that will meet significant technology challenges. It looks for revolutionary breakthroughs that could be transformative of a technology sector.

All of these elements infuse a process where agency program managers develop a vision of a

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[4]Discussion drawn from Bonvillian, *The Connected Science Model in 21st Century Innovation Models* (National Academy Press, 2009), pp. 207, 209, 215.

[5]Warren Bennis and Patricia Ward Beiderman, *Organizing Genius* (Basic Books, 1997).

[6]Carleton, *The Value of Vision in Technological Innovation* (Stanford University dissertation, 2010).

technology advance that could be transformative, then work back to understand the sequence of R&D advances required to get there. If these appear in range of accomplishment, DARPA has processes that allow rapid project approvals by agency directors. This technology visioning process is very different from the way industry undertakes step-by-step downselection of technology options, known as the "stage gate" process, in which budget and market gain are factors used to select which incremental advances to pursue.[7] The visioning process is also very different from the methods used by other Federal R&D organizations, which place more emphasis on research for its own sake. In the context of attempting to bring innovation into legacy sectors, the visioning process may be particularly apt.

2) Use the Island/Bridge Model. Warren G. Bennis and Patricia Ward Biederman have argued that innovation requires locating the innovation entity on an "island" and protecting it from "the suits", the bureaucratic pressures in larger firms or agencies that too frequently repress and unglue the innovation process.[8] But there must also be a "bridge"; the innovation group must be strongly connected to supportive high-ranking decision-makers who can press the innovation forward, providing the needed resources. Sen has argued this is a foundational innovation model.[9]

Island/bridge from the beginning has been a key to DARPA's success, and other innovative organizations use it as well. Lockheed's Skunk Works, and IBM's PC project have exemplified island/bridge at the industry level, severing innovation teams from interference from the business/bureaucratic side.[10] Some of the ideas for this approach came from the way the British organized their wartime labs in the 1940s. While the Skunk Works and IBM PC groups also had strong bridges back to "mainland" decision-makers, Xerox PARC did not, and thus exemplifies the need for the bridge. DARPA exemplifies the island/bridge model at the Federal R&D agency level. It has initiated innovation in frontier sectors, particularly IT, where it operated largely outside the Pentagon's legacy systems, working with and helping to build emerging technology private-sector firms. It has also worked within the defense legacy system. It has operated as an island there but has also used strong links with the Secretary of Defense and other senior defense leaders; these Defense decision-makers helped bridge technology advances from DARPA researchers to the implementing military services.

There are alternative models to island/bridge. In the "open innovation" approach, firms drop reliance on in-house R&D labs and reach out to groups at other, often smaller firms (through acquisitions, technology licensing, or partnerships), or at universities (by linking to public-sector funded researchers at these institutions and licensing their work or creating collaborations).[11] This is primarily, however, a tool for more mature firms that are facing global competition and are less able to afford in-house R&D, or for their rivals, who are attempting to out-compete them.

Robert Rycroft and Don Kash present a similar model but broaden it, arguing that innovation requires "collaborative networks" at a series of levels that must reach outside the organization for a kind of heightened R&D situational awareness. These networks can be less face-to-face and more virtual.[12] Neither approach obviates the need for an originating

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[7]See, for example, R. G., Cooper, S. J. Edgett, and E. J. Kleinschmidt, "Optimizing the Stage Gate Process", *Research Technology Management* (August 2002).

[8]Bennis and Biederman, *Organizing Genius,* p. 206.

[9]Avery Sen, *Transformative Innovation: What 'Totally Radical' and 'Island-Bridge' Mean for NOAA Research*, Dissertation, George Washington University, March 2014.

[10]Ben Rich, *Skunk Works: A Personal Memoir of My Years at Lockheed* (Little Brown/Back Bay Books, 1996); Michael A. Hiltzik, *Dealers of Lightening: Xerox PARC and the Dawn of the Computer Age* (Harper Collins, 1999); James Chposky and Ted Leonsis, *Blue Magic: The People, Power and Politics Behind the IBM Personal Computer* (Facts on File, 1986).

[11]Henry W. Chesborough, "The Era of Open Innovation", *MIT Sloan Review* (April 2003).

[12]Rycroft and Kash, "Innovation Policy for Complex Technologies", *Issues in Science and Technology* (Fall 1999).

innovation "great group" applying an island/bridge approach.

3) Build a Thinking Community. A prerequisite for the ongoing success of the island/bridge is building a community of thought. In science, each contributor stands on the shoulders of others, building new concepts on the foundations of prior ones. Building a sizable "thinking community" has been key to DARPA's success as a source of contributing ideas, as well as talent and political support. Composed of multiple generations of DARPA program managers and researchers working in a field DARPA has supported, this community at its best becomes a group of change agents and advocates. Building a thinking community takes time, but ultimately it reaches a density and mass where ideas start to come faster and faster. For example, in the field of nanotechnology physicist Richard Feynman arguably initiated the community with a 1959 talk entitled "There's Plenty of Room at the Bottom." He urged work at the smallest scale, where quantum properties operate. In 1981 Eric Drexler published the first journal article on the subject, and by 2000 more than 1,800 articles using the term nanotechnology had accumulated, showing that a thinking community had formed and was generating advances at an accelerating rate.

4) Link Technologists to Operators. Another key organizational feature of successful innovation organizations involves connecting the technologists to the operators. This approach was perhaps first exemplified by the relationship between British scientists and military users in developing radar on the eve of World War II. But their success was also recognized and replicated by U.S. scientists and operators during the war.

DARPA then further exemplified the effort to link technologists with operators and transform operations in its work on major defense technology advances. Its work on personal computing and the internet, which shattered the arm's-length relationships in mainframe computing between technologists and operator/users, exhibits the same drive to produce technologies that connect with operators. DARPA's Tactical Technologies Office (TTO) is specifically designed to bring technologies into military tactical systems, using rapid prototyping to transition to air, ground, and naval operators.

Perhaps the most stunning aspect of DARPA's achievement is that it has done it all within a very conservative legacy system: the U.S. military. We could focus on the "stuff" DARPA has midwifed in computing and robotics. But DARPA would not have produced any*thing* innovative had it not operated according to an innovative *process*. So cloning DARPA for non-military purposes isn't about replicating "things" but rather its operations as an innovation organization. Put slightly differently, we need to be interested not in the picture (the output), but in the camera (the method).

Innovation doesn't just happen. Even if the elements for a strong innovation system are assembled, someone or some entity must serve as the catalyst for change. These *change agents* can be persons or organizations. Change agents, like innovation itself, must operate at both the institutional and the personal, face-to-face level. As usual in human affairs, there is no substitute for leadership.

If the front end of the innovation system generally is a prerequisite to innovation in legacy sectors, then the concept of change agent is a requirement as well. So the innovation *system* needs strengthening, including through specific approaches cited here such as critical innovation institutions, island/bridge organization, thinking communities, and linking innovators to operators. But none of these steps alone will implement innovation, particularly in thorny legacy sectors, unless there are institutions and accompanying individuals prepared to act as change agents. Without such change agents, it is hard to see how innovations, particularly in legacy sectors, can emerge out of the innovation pipeline.

The core breakthrough technologies behind the Revolution in Military Affairs in the 1980s and 1990s illustrate that the defense sector has many of the attributes of a legacy sector: The military services resisted precision strike, stealth, and UAVs. Nevertheless, the Defense Department still found a way to put revolutionary technologies into place and bring on significant innovation. Unlike most legacy sectors where breakthrough and disruptive innovations languish, Defense actually implemented them. DARPA alone was not enough to press its advances into the military—it needed change agents, initially led by Defense Secretary Harold Brown and Undersecretary William Perry. If the ultimate question before us is how to create the functional equivalent of DARPA and its allies for other legacy sectors (health care, energy, education, and others), what does the history of Defense Department "offsets" approach tell us about how to do this?

Stealth Aircraft: Air superiority has been a fundamental U.S. defense doctrine since World War II.[13] However, by the late Vietnam War, Soviet air defense systems were making U.S. aircraft ever more vulnerable. This forced the Air Force to employ vast air armadas of mixed-purpose aircraft undertaking jamming and electronic countermeasures, chaff dropping, and radar attacks in order to protect the smaller number of aircraft that were actually undertaking the strike. As early as 1974, the Defense Department's office of the director of defense research and engineering (DDR&E) and DARPA began discussing the development of a "Harvey" aircraft (named after the invisible rabbit in the play and film) that would have a greatly reduced radar, infrared, acoustic, and visual appearance. A Lockheed engineer, Denys Overholser, found the "stealth" answer in a Russian basic research physics paper, DDR&E leaders Malcom Currie and then William Perry pushed the concept, and DARPA got to work on it.

Air Force leaders resisted, seeing limited value in slow and largely unmaneuverable aircraft; they had to be guaranteed that funding for their other aircraft programs would not be affected by the budget for stealth. Encouraged by Perry, Lockheed pushed ahead with the F-117; its performance against a Soviet-supplied air defense system in the Gulf War exceeded expectations. Only the combination of a *critical innovation institution* (DARPA), the *island/bridge* approach of protecting the innovators in DARPA and in Lockheed's Skunkworks but giving them a bridge back to top Defense Department decision-makers, a *thinking community* organized around the challenge, and the *linking of innovators and operators* (at DARPA, at Skunkworks and, when they came around, at the Air Force) was able to overcome the legacy sector forces in the Pentagon. Change agents at the top of the Defense Department were critical.

Precision Strike: The mix of defense capabilities known as "precision strike" was a response to the confrontation between Cold War forces in Europe. Perry formulated precision-strike objectives as the ability to "see all high value targets on the battlefield at any time; make a direct hit on any target we can see; and destroy any target we can hit."[14] Precision strike was at the core of what became known as the Revolution in Military Affairs (RMA); it grew in significant part from Perry's and Harold Brown's drive to develop technology "offsets" to Soviet advantages in numbers. While armies before the RMA had relied on the massed force of as many individual weapons as possible and a few overwhelming nuclear weapons, precision-strike doctrine focused on the ability both to see and to select critical high-value targets and to cripple them rapidly in order to break down the enemy's operating capabilities, without inflicting major casualties on either side or significant civilian casualties. While the wars Clausewitz wrote about were between mass armies inflicting mass casualties on a massive scale, the RMA used precision strike to scale this way back.

To achieve precision strike required "joint" efforts between services. Air Force and Navy weapons systems would have to work in close coordination with Army systems, which is never easy when weapons procurement remains service-controlled. Again, each of the organizing rules cited above came to bear. The Defense Department's efforts began with DARPA working initially outside the service R&D systems, but required pressure from top DoD leaders acting as change agents to implement.

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[13]Details on the three case studies here are in, Richard H. Van Atta, Alethia Cook, Ivars Gutmanis, Michael J. Lippitz, Jasper Lupo, Rob Mahoney, and Jack H. Nunn, *Transformation and Transition*, I, IV, VI, and in the accompanying Detailed Assessments (Institute for Defense Analysis, 2003).

[14]Van Atta *et al.*, *Transformation and Transition*, IV-35; see generally, William J. Perry, "Perry on Precision Strike", *Air Force Magazine* (April 1997).

UAVs: The idea for unmanned aerial vehicles (UAVs, or drones) went through early development stages in both world wars as attack devices, before the advent of guided missiles. There were early Cold War UAV efforts by the Navy and Air Force, and efforts continued until terminated in the 1970s. Despite this halt, today's UAVs are omnipresent on U.S. battlefield and in counterterrorist operations. They undertake a wide range of roles: reconnaissance (using cameras, sensors, and radar), electronic intelligence gathering, long-term surveillance, target designation, communications relays, and, carrying on-board weapons, attacks on specific targets. The U.S. military is approaching the point where it will have more UAVs than manned aircraft. Again, DARPA played a key role in developing the enabling technologies; in the 1970s, it funded R&D in sensors, radar, signal location systems, controls, lightweight and low-visibility airframe structures, long-endurance propulsion, and new operating concepts. Navy Secretary John Lehman, a UAV advocate, provided support for early programs.

But UAVs weren't being developed or produced at a pace where they could make a difference; they weren't scaling up. Using the remarkable performance of RMA technologies in the 1991 Gulf War as proof of the power of advanced technology to transform the battlefield, the Defense Science Board (the Defense Department's leading technical advisory body) called attention to military problems that could be resolved by improved UAV capabilities. In the subsequent Clinton Administration, a trio of defense and intelligence agency leaders, Secretary of Defense William Perry, Undersecretary of Defense John Deutch, and CIA director James Woolsey, pushed for renewed UAV development. In cooperation with DARPA, a new "Advanced Concept Technology Demonstration" (ACTD) process emerged to streamline and accelerate defense technology development and management, but with early cooperation with service users (*linking innovators and operators*). Perry, Deutch, Woolsey, and other DoD *change agents* created a new process—essentially an innovation organization model. It built on DARPA advances (using the island/bridge approach) outside the services, but it involved them in implementing new defense technologies. UAVs were the pilot for this new ACTD approach.

What, then, do these defense case studies tell us about organizing innovation in legacy sectors? It is vital, first, to bring front-end innovation capabilities to influence legacy sectors. An important lesson from DARPA's ability to bring innovation into a defense sector with deep legacy characteristics has been the importance of critical innovation institutions. These institutions should attempt to embody both connected science and technology (linking scientific research to implementation stages) and challenge approaches (pursuing major mission technology challenges). Again, innovation requires not only a process of creating connected science and technology challenges at the institutional level; it also must operate at the personal level. The critical stage of innovation is face-to-face, not institutional, so while there is a need for institutions where talent and R&D come together, personal dynamics, usually embodied in great groups, are a necessity.

The DARPA "right-left" research can be important to reaching the innovation stage, where program managers contemplate the technological breakthroughs they seek to have emerge from the right end of the innovation pipeline, then go back to the left side of the pipeline to look for proposals for the breakthrough research that will get them there. This process tends to lead to revolutionary breakthroughs that could transform a technology sector. A technology "visioning" process at the outset of the effort appears to be a particular key. The approach results in seeking high-risk but high-reward projects.

As discussed, the island/bridge organizational approach for innovation institutions also appears to be important. The innovation team should be put on a protected island apart from bureaucratic influences that can ruin it, so it can focus on the innovation process. The strength of the innovation process will also depend on building a solid thinking community as a source of ideas and support. Because innovation must span numerous steps from research through initial production, means for linking technologists to operators appear to be critical.

Second, change agents will be required to move the innovation toward implementation.

DARPA alone was not enough. Unlike most legacy sectors, the Defense Department has an official, the Secretary of Defense, by law a civilian, who can exercise authority to force change. If the Secretary sees the need for a technology shift, he or she can muster the power to direct it despite all the legacy-sector checks in the system. DARPA has been successful when it ties its technological advances to a senior defense leader in the Office of the Secretary who is prepared to override legacy pressures and be a change agent. Of course, the Defense Department faced an additional intense pressure for change—meeting national security needs—but these two characteristics, a strong front-end innovation system linked to change agents, remain central.

There are important lessons here for other legacy sectors: a "connected" innovation agency, using the "extended pipeline" model that is outside the legacy system, and then linked to a source of power that can direct change—a change agent—has proved to be a vital combination in the defense sector's ability to innovate. The long-standing perspective on DARPA has been that its successes have been in the "frontier" sector; it is rightly acclaimed for its foundational role in the IT revolution. But there is a less well understood perspective on DARPA that is the other side of the coin: It has brought disruptive, radical innovation into a legacy sector's organization routines and model too.

So DARPA doesn't only belong in the "extended pipeline" model; it also has developed features that have enabled it to innovate in a legacy sector. It has displayed key features of the "innovation organization" model. Legacy sectors use political, technological, economic, and social system barriers in their defense against disruptive innovation. The innovation organization model recognizes that there are many institutions and mechanisms operating within an innovation system, particularly in legacy sectors. This mandates a richer evaluation of innovation and of potential policies to shift the overall system. DARPA and its senior Department allies have found ways to impose this richer mix of polices. This mix of strong front-end innovation capability and change agents provides basic lessons for innovation in other legacy sectors that go far beyond defense to other key parts of the economy.

Obviously, the Defense Department is a special environment, and the defense industry is special on account of it. DoD leaders have now embarked on a new "defense innovation initiative" to develop a new generation of "offset" technologies. They have indicated they will be pursuing major technology development efforts in cyber security, undersea capabilities, air dominance, and space. They are now at work developing technology strategies in each area. However, this effort will not bear fruit unless the lessons for innovation organization in legacy sectors from the last "offsets" strategy are studied and adapted. Since most of the economy resides in legacy sectors often in sore need of innovation advances, these lessons on "transformative innovation" also have much wider application to other sectors.

> Concern over service resistance to revolutionary change led Marshall to begin thinking about the problem of bringing about innovation in large organizations—in this case the U.S. military. . . . Convinced that a major shift in how future wars would be fought was in the offing, and recognizing that in the wake of Desert Storm the services would see little need for major innovation, Marshall began encouraging members of St. Andrew's Prep and other scholars to explore past examples of successful innovation.
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> **—Andrew Krepenevich and Barry Watts,**
> *The Last Warrior: Andrew Marshall and the Shaping of Modern American Defense Strategy* (2015), p. 204