PUBLIC PROCUREMENT AND DISRUPTIVE TECHNOLOGIES: DARPA'S ROLE IN THE DEVELOPMENT OF mRNA VACCINES[1]

Contratación pública y tecnologías disruptivas: el papel de DARPA en el desarrollo de vacunas de ARNm

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RESUMEN: Uno de los propósitos clave del Departamento de Defensa de los Estados Unidos (DoD) es proporcionar capacidades para ganar la guerra a soldados, marineros, infantes de marina, aviadores y guardianes. Debido a la naturaleza única de la adquisición de defensa, esto requiere una constante innovación. Desde la década de 1950, cuando la tecnología militar se volvió demasiado sofisticada para los arsenales gubernamentales, el DoD ha confiado principalmente en contratistas del sector privado altamente especializados. Sin embargo, para ciertas inversiones en ciencia básica o para sortear fallas del mercado, el DoD destina recursos a sus propios esfuerzos de investigación y desarrollo. La institución gubernamental más famosa de estas es la Agencia de Proyectos de Investigación Avanzada de Defensa (DARPA), cuyas invenciones han incluido aviones furtivos, sistemas de posicionamiento global e internet. Sin embargo, como ocurre en la mayoría de los países, una gran parte de la innovación se queda en el sector privado. Este artículo explora lo que hace excepcional a DARPA, examinando su papel en el desarrollo de tecnologías de ARNm utilizadas posteriormente para desarrollar vacunas contra el COVID-19. Y advierte que DARPA puede no ser escalable.

PALABRAS CLAVE: DARPA; tecnologias disruptivas; contratación pública; vacunas mRNA.

ABSTRACT: One of the key purposes of the U.S. Department of Defense (DoD) is to deliver war-winning capabilities to soldiers, sailors, marines, airmen, and guardians. Because of the unique nature of defense procurement, this requires constant innovation. Since the 1950s, when military technology became too sophisticated for government arsenals, the DoD has primarily relied on highly specialized defense contractors in the private sector. However, for certain investments in basic science or to circumvent market failures, the DoD devotes resources to its own research and development efforts. The most famous of these government institutions is the Defense Advanced Research Projects Agency (DARPA), whose inventions have included stealth aircraft, global positioning

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systems, and the internet. Nevertheless, as in most countries, most innovation occurs in the private sector. This article explores what makes DARPA exceptional, examining its role in the development of mRNA technologies later used to develop COVID-19 vaccines. And it cautions that DARPA may not be scalable.

KEYWORDS: DARPA; disruptive technologies; public procurement; mRNA vaccines.

I.- INTRODUCTION

The first reliable heavier-than-air machine was invented in Dayton, Ohio. Its creators did not work for the U.S. government nor were their research and development costs subsidized. Instead, they were private entrepreneurs.[3] Not only was the U.S. government uninvolved in the development of the airplane, the Army was at first indifferent to this unproven machine.[4] Only when the Wright brothers had almost sold their flying machine to the French government did the United States reconsider.[5] This story illustrates an axiom in the literature: government investment is generally not the best way to stimulate technological innovation.[6]

A half century later, Soviet launched the first satellite into orbit. Americans were terrified. A mere 12 years later, the U.S. space technology had surpassed the Russians and America put the first man on the moon. In one of the great ironies of history, in the epic battle between free market and communist systems, America achieved this great technological leap not by dint of its capitalist innovators but because U.S. government

[3] RIDLEY, M.; *How Innovation Works: And Why It Flourishes in Freedom*, New York, Harper, 2020, pp. 95-103, contrasting the War Department's $50,000 funding of the experiments with powered flight by Samuel Langley and his spectacular failure with the Wright brothers: "Where Langley had done everything wrong . . . the Wrights had done everything right," which included doing their work without any government investments.
[4] MCCULLOUGH, D.; *The Wright Brothers*, New York, Simon & Schuster, 2016., pp. 138, 153-54.
[5] *Id.*, pp. 152, 174-75. After lengthy negotiations, the Wright brothers ultimately signed a contract with the U.S. Army just one month before finalizing a contract with France. *Id.*, p. 188. See also SCHOONER, S.L. and CASTELLANO, N.E.; "Reinvigorating Innovation: Lessons Learned from the Wright Brothers", *Contract Management*, n° 56, April 2016, pp. 46, 53, suggesting that the brothers' sense of patriotic duty led them to give the U.S. government a final chance before taking their wares to Europe. Again rebuffed, they traveled to France where public demonstrations of their flying machine were widely celebrated, and this ultimately persuaded the U.S. government of its value. *Id*.
[6] For example, see RIDLEY, *supra* note 3, at 275-82, describing innovation as a "bottom-up" phenomenon that central planners cannot coordinate effectively. But see MAZZUCATO, M.; *The Entrepreneurial State: Debunking Public vs. Private Sector Myths*, New York, Hachette, 2018, making the opposite argument and claiming the U.S. government has been the key driver of the United States' innovation in the last half century.

proved a better central planner.[7] A private sector innovator like Elon Musk did not put the first man on the moon. NASA did. Another Sputnik progeny was the Defense Advanced Research Projects Agency (DARPA), founded in 1958. To a greater extent than NASA, whose infamous launch failures in 1987 and 2005 undermined its credibility, no other federal U.S. government agency has earned a greater reputation for delivering innovation.[8] DARPA, then, seems like an exception to the rule that one typically does not look to the government for innovation. Is DARPA different?

To answer this question, this article reviews a recent example: DARPA's contribution to the groundbreaking mRNA technology that last year supported the development of COVID-19 vaccines at unprecedented speed. It then considers whether DARPA's success is replicable. We may be tempted to build more DARPAs, but caution is warranted. DARPA has certain institutional features that have worked well for solving some problems, but we do not fully understand its workings – or else its success would have already been reproduced across the U.S. government and indeed the entire world. Attempts to do so may be a costly reminder that DARPA is the exception that proves the rule: governments are not typically the principal drivers of innovation. This article unpacks what makes DARPA special, describes how Operation Ward Speed (OWS) followed a similar model, discusses some of the literature on public versus private innovation, and concludes with a word of caution about public research.

II.- DARPA AND THE DEVELOPMENT OF mRNA VACCINE TECHNOLOGY

The COVID-19 pandemic has presented a challenge almost unprecedented in living memory. Developing new vaccines usually takes a minimum of ten years. Yet only months after the crisis went global, teams of researchers in the United States, the UK, and Germany had developed effective vaccines. This was an astounding accomplishment. And it was not only a private-sector accomplishment.[9] The U.S. government played a critical role.[10] In particular, DARPA both had previously funded the development of mRNA technologies for creating vaccines and also served as a model for the organizational structure of Operation Warp Speed (known by the abbreviation "OWS"

[7] *The Economist*, "The New Space Race", 20 January 2018, https://www.economist.com/leaders/2018/01/18/the-new-space-race, observing that the Apollo mission "was probably the most centrally planned operation in the history of the United States".

[8] "Innovation" in the context of public procurement can refer to significantly improved goods or services, the use of innovative suppliers, or to improvements the procurement process itself. YUKINS, C.R. and RACCA, G.M.; *Joint Public Procurement and Innovation: Lessons Across Borders*, Brussels, Bruylant, 2019, pp. 2, 7, 9. All three are touched on, but this article is mainly about the first category of public procurement innovation: the research and development of innovative products.

[9] ADLER, D.; "Inside Operation Warp Speed: A New Model for Industrial Policy", *American Affairs*, volume 5, n° 2, summer, 2021, p. 6, concluding that to claim that the rapid development of a coronavirus vaccine was *only* the work of the private sector would be as absurd as saying that the Manhattan Project was.

[10] MANGO, P.; *Warp Speed: Inside the Operation that Beat COVID, the Critics, and the Odds*, New York, Republic, 2022, pp. 25-51, describing the role of government officials in the success of OWS. For example, the logistics and contracting support were provided by the DoD. *Id.*, pp. 17, 66.

for those words in English), the task force assigned to expedite development of COVID vaccines.

Until recently, vaccine development had languished for decades. That is because creating new vaccines is expensive, profit margins are thin for such single-use medications,[11] and, given those slim margins, pharmaceutical firms were especially sensitive to litigation risk:[12] classic market failure.[13] Absent incentives, production methods lagged behind the science.[14] This limited rapid production even for proven vaccines.

With friendly neighbors to our north and south, the U.S. Department of Defense (DoD) is primarily an expeditionary force.[15] The U.S. armed forces fight not at home, but are deployed around the world, often on short notice. This exposes warfighters to rare diseases, both from naturally occurring pathogens and from man-made biological weapons. Creating a capability for rapidly designing and producing vaccines *en masse* is thus a priority. Enter DARPA.[16]

When Dan Wattendorf arrived at DARPA's biological technologies office in 2010, mRNA technology already existed. The possibility of using the body's own DNA for producing vaccines was recognized as early as 1950. In 2005, Katalin Karikó and Drew Weissman discovered a way to alter mRNA that would increase its therapeutic potential. Wattendorf sought to stimulate research into lipid-based mRNA delivery systems.[17] Even with financial support, large pharmaceutical companies still weren't interested. Wattendorf turned to newer biotech companies, and in 2013 DARPA issued a $25 million grant to a company, which is now a household name: Moderna.[18] As its name would imply (given that the last there letters spell out "RNA" in English), it concentrated on using mRNA to develop human vaccines.[19] By 2019, it had produced the first effective vaccine using mRNA technology.[20] Thus, the fact that DARPA had already made key investments in vaccines pre-COVID underlay the unbelievably rapid pace of OWS.[21]

[11] ADLER, *supra* note 9, pp. 3, 10.
[12] *The Economist*, "Shot in the Arm", 24 May 2003, https://www.economist.com/business/2003/05/22/shot-in-the-arm.
[13] SALINSKY, E. and WERBLE, C.; "The Vaccine Industry: Does It Need a Shot in the Arm?", Background Paper, *National Health Policy Forum*, 25 January 2006, https://hsrc.himmelfarb.gwu.edu/cgi/viewcontent.cgi? article=1158&context=sphhs_centers_nhpf, pp. 12-22.
[14] ADLER, *supra* note 9, p. 10, explaining that until the advent of mRNA production, vaccines were made from pathogens grown using chicken eggs and bioreactors, a process that was slow, unwieldy, and not scalable.
[15] REVERON, D.S., GVOSDEV, N.K., and OWENS, M.T.; *U.S. Foreign Policy and Defense Strategy: The Evolution of an Incidental Superpower*, Washington, Georgetown University Press, 2015, p. 5.
[16] ADLER, *supra* note 9, pp. 9, 11, "Soldiers go everywhere. One of the biggest threats they face is infectious disease."
[17] *Id.*, p. 10.
[18] *Id.*, pp. 11-12.
[19] *Id.*, p. 12.
[20] *Id.*, explaining that Moderna's first successful vaccine was for the chikungunya virus.
[21] *Id.*, p. 7. As an infectious disease specialist at Harvard Medical School, Michael Callahan, explained, OWS "could not have happened if the technology had not been developed to move this quickly. We got very lucky with mRNA." *Id.*, pp. 14-15. Thus, "the mRNA technology platform enabled vaccine design to be finished in days, not months or years, as in the past." MANGO, *supra* note 10, p. 5.

Vaccines usually take at least a decade from development to approval; by contrast, the Pfizer and Moderna vaccines were approved in December 2020, just seven months.[22] This was an astounding accomplishment.

Apart from its support of mRNA vaccine research a decade before the coronavirus struck, DARPA's organizational structure also served as a model for OWS.[23] OWS was launched on May 15, 2020, and this signaled a partnership between the Department of Health and Human Services, the DoD, and pharmaceutical companies.[24] Several key features of DARPA's structure were incorporated.

DARPA has been credited with several transformative technologies, including ARPANET (the internet), the engines that powered the Apollo missions, GPS, and flat panel displays.[25] One secret of its success lay in doing "connected science". Rather than conducting only basic research, DARPA prides itself in simultaneously mobilizing private-sector production, "enabling full innovation not simply invention."[26] This is a key feature of the DARPA model.

The DARPA model entails several other key elements. First, it is small, composed of only 50–100 program managers.[27] Second, unlike most military organizations, its structure eliminates the typical hierarchy and has only two levels, which fosters cooperation.[28] Third, its technical staff are employed by DARPA for at most 3–5 years, encouraging fresh thinking and reducing careerism.[29] Fourth, it uses a "portfolio approach", funding multiple lines of research in parallel, knowing many of these will surely fail.[30] Last, DARPA utilizes flexible contracting procedures, especially the renowned "Other Transactions Authority" (OTA).[31]

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[22] ADLER, *supra* note 9, p. 15, also noting that the new mRNA technology allowed Moderna to design its vaccine in just two days. That is, the Chinese virology team released the genetic sequencing of the coronavirus on a Friday, and by Monday Modern had already designed a vaccine. MANGO, *supra* note 10, p. 13.

[23] ADLER, *supra* note 9, p. 12, quoting Matthew Hepburn, who led coronavirus vaccine development effort: "OWS is DARPA at scale."

[24] SLAOUI, M. and HEPBURN, M.; "Developing Safe and Effective Covid Vaccines – Operation Warp Speed's Strategy and Approach", *New England Journal of Medicine*, volume 383, n° 18, 2020, p. 1701.

[25] ADLER, *supra* note 9, p. 7.

[26] BONVILLIAN, W.B., VAN ATTA, R., and WINDHAM, P.; *The DARPA Model for Transformative Technologies: Perspectives on the U.S. Defense Advanced Research Agency*, Cambridge, UK, Open Book, 2019, p. 98. Perhaps the best example of this "connected science" approach was its commitment to making ARPANET into a commercially viable product, by creating and demonstrating a complete system. *Id.*, p. 19.

[27] *Id.*, pp. 99, 335.

[28] *Id.*, pp. 17-18, 99, 335.

[29] *Id.*, pp. 100, 335.

[30] *Id.*, pp. 11, 14-16, 336.

[31] *Id.*, pp. 20, 99, 335. OTAs are a form of contract that is not subject to many of the statutes and regulations that government most federal contracts are subject to, that are usually for scientific research and development, and that were originally described by statute as "a more permissible form of contract". NASH, R.C., O'BRIEN-DEBAKEY, K.R., SCHOONER S.L., and EDWARDS, V.J.; *The Government Contracts Reference Book: A Comprehensive Guide to the Language of Procurement*, New York, Wolters Kluwer, 2021, p. 345.

And yet DARPA and OWS were quite different: the former has a defense mission, the latter public health; the one was concerned with over-the-horizon threats decades away, the other with a present-day crisis; and DARPA's $3.4 billion budget was a sixth of OWS's price tag.[32] Notwithstanding such disparities, OWS followed the DARPA model to the extent possible.[33] OWS was aggressively high risk in pursuit of rapid results. It used a portfolio approach, having several competing programs in parallel.[34] Its structure was flat and project oriented.[35] And not least it the use of the same flexible contracting vehicle, the OTA.[36]

The portfolio approach was critical to OWS's success. This encompassed a diverse strategy, with four platform technologies and two vaccine developers each.[37] This mitigated the risk.[38] Later, when a fourth effort failed (replicating live-vector technology), progress continued apace because OWS hedged by investing in research for several competing technologies.[39] In addition to successful mRNA efforts, parallel efforts paid off with research that sought to build an adenovirus using replication-defective live-vector technology, the results of which were a "triumph of genetic engineering".[40] Many credit attempting multiple development processes in parallel rather than sequentially as the key to OWS's rapid progress.[41]

OWS's contracting methodology has also been hailed as a best practice.[42] As noted above, like DARPA, OWS bypassed the usual procurement regulations by employing

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[32] ADLER, *supra* note 9, p. 9.
[33] *Id.*
[34] *Id.*
[35] *Id.* See also MANGO, *supra* note 10, pp. 26, 28-29, praising OWS's organizational structure and independence from what could have been micromanaging from the White House; BADGER, D. and MOFFIT, R.E.; "COVID-19 and Federalism: Public Officials' Accountability and Comparative Performance", *Heritage Foundation Backgrounder*, Domestic Policy Studies, n° 3638, July 26, 2021, p. 6, suggesting that OWS functioned consistent with the Trump administration's emphasis on decentralizing regulatory power.
[36] ADLER, *supra* note 9, p. 9.
[37] SLAOUI and HEPBURN, *supra* note 24, p. 1702.
[38] *Id.* Although the news reports have concentrated on the success of mRNA technology, what was ingenious about the OWS approach was the investment in multiple technological platforms – because no one could know beforehand which one would work. MANGO, *supra* note 10, p. 20.
[39] ADLER, *supra* note 9, pp. 13-14.
[40] *Id.*, p. 14.
[41] *Id.*, p. 13. OWS's portfolio approach incorporated redundancies in two senses. As noted above, it financed research along several distinct lines of effort with six companies: Moderna, Janssen, AstraZeneca, Sanofi, and Novavax. The sixth company, Pfizer, initially declined such support. MANGO, *supra* note 10, pp. 20, 27; GRIFFIN, R. and ARMSTRONG, D.; "Pfizer Vaccine's Funding Came from Berlin, Not Washington", *Bloomberg*, 9 November 2020, https://www.bloomberg.com/news/articles/20 20-11-09/pfizer-vaccine-s-funding-came-from-berlin-not-washington?sref=cD53rqQH. Second, OWS also paid for the untested vaccines in advance. In essence, the contracts said the government would buy a certain number of doses regardless of whether the vaccine was approved by the Food and Drug Administration (FDA). Advance purchases accelerate manufacturing. When Pfizer received FDA approval, vaccines shipped within 24 hours. That was unheard of. Normally, manufacturing would begin only after FDA approval. I am grateful Ashley Ruhe for the contents of this footnote (correspondence on file with the author).
[42] ADLER, *supra* note 9, pp. 4, 15-16.

OTAs.[43] This afforded OWS with greater speed and flexibility.[44] Further, OTAs are thought to attract innovative companies that otherwise would not have sought to do business with the federal government.[45] Yet using OTAs is not risk free. They no doubt afford flexibility, but they do so at the expense of certainty when litigation arises.[46] A second contracting mechanism that contributed to the success of the OWS program was the use of the Defense Production Act (DPA).[47] This authority grants the president vast powers to conscript private enterprise for war efforts, and it was used to great effect here.[48] Some recommend expanding its use when Silicon Valley won't cooperate.[49] Yet such measures are heavy-handed and should be used sparingly lest they discourage non-defense economic activity.[50] Thus, such "best practices", though effective in the contexts of DARPA or OWS, may not be transferable more broadly.[51]

III.- IS DARPA'S SUCCESS REPLICABLE?

DARPA's success has not gone unnoticed. Bipartisan efforts have already created two more "DARPAs" for non-defense innovation: IARPA for intelligence in 2007[52] and ARPA-E for energy in 2009.[53] And a third DARPA-type institution may be on the way: in 2021, President Biden announced plans for "ARPA-H", which would be dedicated to

[43] *Id.*, p. 16.
[44] *Id.*
[45] U.S. Government Accountability Office, "COVID-19: Federal Efforts Accelerate Vaccine and Therapeutic Development, but More Transparency Needed on Emergency Use Authorizations", November 2020, https://ww w.gao.gov/assets/gao-21-207.pdf, p. 14.
[46] CASTELLANO, N.E.; "'Other Transactions' Are Government Contracts, And Why It Matters, *Public Contract Law Journal*, volume 48, n° 3, spring 2019, pp. 486-514.
[47] ADLER, *supra* note 9, p. 17.
[48] The DPA was especially helpful to facilitate mass production. Creating one vial of vaccine is one challenge; manufacturing vaccines at scale is another; doing so when there was a worldwide shortage of glass vials, diluent, and syringes compounded the problems further. The DPA proved useful in that it required companies to prioritize rated orders throughout the supply chain, forcing even subcontractors to prioritize such rated orders. My appreciation to Ashley Ruhe for the material in this footnote (correspondence on file with the author). For more on OWS's use of the DPA, see also MANGO, *supra* note 10, pp. 81-83.
[49] LETENDRE, L.; "Google . . . It Ain't Ford: Why the United States Needs a Better Approach to Leveraging the Robotics Industry", *Air Force Law Review*, n° 77, 2017, pp. 51-64.
[50] See SCHOENI, D.; "Three Options for Acquiring Innovation" *Air & Space Power Journal*, volume 32, n° 4, winter 2018, pp. 85, 86-89, criticizing Letendre's recommendation for an increased use of the DPA as coercive.
[51] Standing in contrast to the success of the OWS was the European Commission, which lacked procurement experience. *The Economist*, "Why the EU's Covid-19 Vaccination Programme Went Wrong", 31 March 2021, https://www.economist.com/briefing/2021/03/31/why-the-eus-covid-19-vaccination-programme-went-wrong. See also ADLER, *supra* note 9, p. 17.
[52] BONVILLIAN, W.B.; "IARPA: A Modified DARPA Innovation Model", in BONVILLIAN, W.B., VAN ATTA, R., and WINDHAM, P.; *The DARPA Model for Transformative Technologies: Perspectives on the U.S. Defense Advanced Research Agency*, Cambridge, UK, Open Book, 2019, pp. 435-52.
[53] BONVILLIAN, W.B. and VAN ATTA, R.; "ARPA-E and DARPA: Applying the DARPA Model to Energy Innovation", in BONVILLIAN, W.B., VAN ATTA, R., and WINDHAM, P.; *The DARPA Model for Transformative Technologies: Perspectives on the U.S. Defense Advanced Research Agency*, Cambridge, UK, Open Book, 2019, pp. 361, 363.

healthcare research.[54] Further, building on the success of OWS in assisting with the rapid development of vaccines, some have even called for even more DARPAs across the whole of government and argued that "[t]he possibilities are almost endless."[55] But are they?

Enthusiasm about DARPA is emblematic of a broader fad for state-sponsored industrial policy and its potential for delivering technological innovation.[56] This view has no greater advocate than Mariana Mazzucato, whose 2013 book *The Entrepreneurial State* has become popular among policymakers who favor state intervention.[57] She argues government-funded research with "mission-directed directionality" has been the primary source of innovation.[58] There are, however, several reasons for skepticism.

Evidence proves a *negative* correlation exists between public research and economic growth. In 2003, the OECD published a report saying as much, though the authors were apparently surprised by what the data showed.[59] José Luis Ricón Fernández has written that if one lesson can be drawn from the experience with industrial policy, it is that its success is "dependent on which industry, which country, in which period of development it is applied."[60] The return on such spending is thus uncertain. A recent book on using public procurement to stimulate innovation concluded by admitting that evidence that such policies work is at best inconclusive.[61] Governments cannot simply "buy" innovation by spending more on research. Would that the path to economic growth were so straightforward.

Mazzucato concentrates only on America in the last half century.[62] She excludes nineteenth century Britain, where the industrial revolution originated. This is a crucial counterexample. Britain lacked any discernible economic growth policy and yet led the world in innovations.[63] Similarly, until 1940 the U.S. government spending on research and development was paltry, and yet during that *laissez faire* era America produced

[54] TOLLEFSON, J.; "What the Rise of 'ARPA-Everything' Will Mean for Science", *Nature*, n° 595, 22 July 2021, p. 483.
[55] ADLER, *supra* note 9, p. 27, suggesting the best opportunities lie where the government is a major purchaser. Specifically, he argues for interventions for microchips, batteries, merchant shipbuilding, and high-speed rails.
[56] RIDLEY, *supra* note 3, p. 275.
[57] MAZZUCATO, *supra* note 6.
[58] *Id.*, pp. 5-8, 45-48.
[59] OECD, *Sources of Economic Growth in OECD Countries* (2003), https://www.oecd-ilibrary.org/economics /the-sources-of-economic-growth-in-oecd-countries_9789264199460-en, pp. 84-85.
[60] SCHNEIDER, J.; "Rethinking Industrial Policy with Nintil", *ChinaTalk*, summary of a podcast with José Luis Ricón Fernández, 18 February 2021, https://chinatalk.substack.com/p/rethinking-industrial-policy-with.
[61] LEMBER, V., RAINER, K., and KALVET, T.; "How Governments Support Innovation through Public Procurement: Comparing Evidence from 11 Countries" in LEMBER, V., RAINER, K., and KALVET, T., *Public Procurement, Innovation and Policy: International Perspectives*, Springer, Heidelberg, 2013, p. 307.
[62] MINGARDI, A., "A Critique of Mazzucato's Entrepreneurial State", *Cato Journal*, volume 25, n° 3, fall 2015, pp. 603, 608.
[63] MOKYR, J.; *The British Industrial Revolution: An Economic Perspective*, New York, Routledge, 1999, p. 7.

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world-famous innovators such as Edison, the Wright brothers, Bell, and Tesla.[64] Further, during the twentieth century government spending quadrupled, increasing from 10 to 40 percent of GDP, to such a degree that it would actually be surprising if these enlarged states *did not* create some innovation.[65] And by concentrating on late twentieth century America, Mazzucato dismisses the well-documented experience of many countries, where public research and development has been, in general, disappointing.[66]

Last, Mazzucato's argument relies on the premise that the government cannot only produce innovation but can also choose what form it will take ("directionality").[67] One chapter of her book discusses myriad ways that the U.S. government subsidizes innovation.[68] DARPA receives a section of its own,[69] to which she attributes all manner of innovations.[70] Some credit is due, of course. With the introduction of ARPANET, DARPA undoubtedly helped to invent some of the core technologies and laid the foundation for the internet. Yet to single out DARPA for praise and to ignore the important contributions of Corning, Cisco, Netscape, Google, and Amazon is disingenuous.[71] Further, DARPA is reasonably good at defense innovation and sometimes useful spillover technology or by-products may result.[72] But that is not the sort of "intentional" government-sponsored innovation that Mazzucato advocates.[73] Those who would claim that the spillovers themselves make public spending on innovation worthwhile fail to adduce sufficient evidence to support that claim.[74] Worse, public research displaces private research, decreasing the overall level of innovation.[75]

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[64] KEALEY, T.; "The Case Against Public Science", *Cato Unbound*, 5 August 2013, https://www.cato-unbound .org/2013/08/05/terence-kealey/case-against-public-science.
[65] MINGARDI, *supra* note 62, p. 608.
[66] OECD, *supra* note 59, pp. 56-58, 69, 84-85, reviewing a data set from 21 OECD countries over the 1971-98 period and finding that public spending on research spending did not increase long-term economic growth; LEMBER, RAINER, and KALVET, *supra* note 61, p. 307, summarizing the results 11 country studies on the effect of public procurement policies designed to promote innovation and economic growth and reporting that with only a few exceptions such policies were largely unsuccessful; MINGARDI, *supra* note 62, pp. 604-05, observing that Mazzucato avoids discussing the experience of Europe's social democracies' industrial policies, which has been mostly disappointing; KEALEY, *supra* note 64, describing massive public spending on research and development in Germany and France in the nineteenth century, which never equalled the dynamism or innovation to be found in Britain and America despite the negligible public spending in the latter two countries.
[67] That is, that the government is capable of what she calls "mission-directed directionality". MAZZUCATO, *supra* note 6, 5-8, 45-48.
[68] *Id.*, pp. 79-92.
[69] *Id.*, pp. 80-84.
[70] *Id.*, pp. 34, 81-84, 143-44.
[71] RIDLEY, *supra* note 3, at 278. See also MINGARDI, *supra* note 62, pp. 610-12.
[72] RIDLEY, *supra* note 3, at 278.
[73] MINGARDI, *supra* note 62, p. 613, arguing that Mazzucato confuses intended and unintended consequences.
[74] MCCLOSKEY, D.N. and MINGARDI, A.; *The Myth of the Entrepreneurial State*, AEI Press, Washington, 2013, pp. 123-30, noting that some argue that industry policy supports positive externalities, spillovers, and faster economic growth but there is a lack of rigorous and systemic empirical analyses of such questions.
[75] PARK, W.G.; "International R&D Spillovers and OECD Economic Growth", *Economic Inquiry*, volume 33, n° 4, 1995, pp. 581-82, finding that the effect of public research is weakly negative and suggesting that this may be caused by the crowding out effect.

For these reasons, Mazzucato's starry-eyed account of DARPA's contribution to U.S. innovation is incomplete.

DARPA fanatics neglect Hayek's knowledge problem. Economic knowledge is dispersed.[76] Even DARPA geniuses cannot possibly know what society as a whole knows collectively. No central planner, no matter how intelligent, can know what the next "big" innovation will be. Free markets have proven more adept at driving innovation than any other arrangement.[77] DARPA fills a gap where a normal market is absent – essential work in this rarified context.[78] Yet scaling up DARPA to stimulate innovation more broadly would mirror failed industrial policies of the past.[79] This path will surely disappoint.

Even if enthusiasm for DARPA and for industrial policies generally are misguided, perhaps there are still lessons that defense procurement can teach. As the last paragraph suggested, DARPA has succeeded in its unique context, one in which the free market does not operate. The next section describes the unique conditions of the defense procurement market and then suggests that perhaps certain lessons can be learned with broader applications to other sectors – though these lessons are probably narrower than what DARPA enthusiasts would suggest.

IV.- CAN WE LEARN SOMETHING FROM DEFENSE ACQUISITIONS?

Defense procurement encompasses both civil goods available "off the shelf" and specialized military equipment. The latter forms defense procurement's core, which is characterized by complex technologies.[80] Indeed, the nature of defense entails an "endless quest for the technological frontier."[81] Rivals are in a constant state of competition for

[76] The knowledge required to best allocate scarce resources "never exists in concentrated or integrated form, but solely as the dispersed bits of incomplete and frequently contradictory knowledge which all the separate individuals possess." HAYEK, F.A.; "The Use of Knowledge in Society", *American Economic Review*, volume 35, n° 4, 1945, p. 519. Central planners cannot master this information because it is constantly changing: "The continuous flow of goods and services is maintained by constant deliberate adjustments, by new dispositions made every day in the light of circumstances not known the day before, by B stepping in at once when A fails to deliver." *Id.*, p. 524.

[77] Socialist or other centrally planned economies are, by contrast, "fatally lacking in dynamism." PHELPS, E.; *Mass Flourishing: How Grassroots Innovation Created Jobs, Challenge, and Change*, Princeton, New Jersey, Princeton University Press, 2013, p. 127.

[78] TAYLOR, T.; "Competition in Defence Practice: Theory and Reality", in BURGESS, K. and ANTILL, P., *Emerging Strategies in Defense Acquisitions and Military Procurement*, Hershey, Pennsylvania, IGI Global, 2017, pp. 33-34, arguing that because of imperfect market conditions, traditional competition does not exist for the defense procurements involving significant technological development, high risk, and large sums of money.

[79] RIDLEY, *supra* note 3, p. 280.

[80] GEORGOPOULOS, A.; "The EDA and EU Defence Procurement Integration", in KARAMPEKIOS, N. & OIKONOMOU, I., *The European Defence Agency: Arming Europe*, New York, Routledge, 2015, p. 119.

[81] BELLAIS, R. and DROFF, J.; "Innovation, Technology and Defence Procurement: Reform or Paradigmatic Shift?", in BURGESS, K. and ANTILL, P., *Emerging Strategies in Defense Acquisitions and Military Procurement*, Hershey, Pennsylvania, IGI Global, 2017, p. 209.

superior weaponry in order to render their adversaries' weaponry obsolete.[82] "No weapon system is immune to the perennial gale of competition from potentially superior technical substitutes."[83]

Because it is so dependent on innovation, defense procurement is an unpredictable business. Any technological innovation entails great uncertainty.[84] But the level of uncertainty here is of an "entirely different order of magnitude".[85] When purchasing products with extensive developmental requirements, traditional procurement does not work, and that is true as much for the private sector as for the public.[86] When purchasing complex products, private sector buyers experience the very same challenges.[87] So when private firms attempt to push the state-of-the-art in a rapid fashion, they likewise encounter weapons-like problems.[88]

The private sector rarely attempts "moon shots".[89] But when they do, "Commercial business practice is more likely to learn from weapons development than the other way around."[90] That provocative conclusion was written almost six decades ago by researchers at Harvard Business School, who wrote one of the classics on the economics of defense procurement. Generally, lessons about best practices are thought to travel in the other direction, from business to government. Yet the authors of this study argue that, in fact, most private firms lack *any* experience relevant or transferable to the field of advanced weapons procurement.[91] In the last sentence of their book, the authors conclude with another thought-provoking comment about this striking role reversal: "Should there be a case a rapidly accelerated rate of technological change in the commercial sector of the economy, the weapons acquisition process may provide a valuable source of experience and ideas for business generally."[92]

What, then, can be learned from defense procurement? First, care must be taken to avoid sharing lessons that are disanalogous between the public and private sectors and also between different types of public procurement. The nature of the DoD's purchases is

[82] An old television still works. Its value depends only on its own internal characteristics. In contrast, arms are a *relational* good. Their value depends on their relative performance. If a foe's advances supersede existing arms, they may be rendered useless. KIRKPATRICK, D.L.I.; "Trends in the Costs of Weapon Systems and the Consequences", *Defence and Peace Economics*, volume 15, n° 3, 2004, p. 265. Defense procurement is thus a uniquely competitive environment.
[83] SCHERER, F.M.; *The Weapons Acquisition Process: An Economic Analysis*, Boston, Harvard Business School, 1964, p. 19.
[84] PECK, M.J. and SCHERER, F.M.; *The Weapons Acquisition Process: An Economic Analysis*, Boston, Harvard Business School, 1962, p. 29, "The essence of invention is great unpredictability."
[85] *Id.*, pp. 44-45.
[86] TAYLOR, *supra* note 78, p. 33.
[87] MARKOWSKI, S., HALL, P., and WYLIE, R., *Defence Procurement and Industry Policy: A Small Country Perspective*, New York, Routledge 2010, p. 51; BAJARI, P. and TADELIS, S.; "Incentives and Award Procedures: Competitive Tendering vs. Negotiations in Procurement", in DIMITRI, N., PIGA, G., and SPAGNOLO, G., *Handbook of Procurement*, Cambridge University Press, Cambridge, 2006, pp. 123-24.
[88] PECK and SCHERER, *supra* note 84, pp. 583-84.
[89] *Id.*, p. 9.
[90] *Id.*
[91] *Id.*, p. 584.
[92] *Id.*, p. 595.

distinct from that of civilian agencies. Its procurement methods, therefore, are calibrated to push the state-of-the-art and thereby maintain a technological advantage over its adversaries. It is in a sense always in crisis mode. That is probably not the best way to run other agencies, especially for those more sensitive to cost pressures, nor to stimulate *routine* innovation. DARPA is thus a solution to an incurable market failure and at most a second-best solution to DoD-specific problems. Such sectoral-specific solutions to failures unique to the defense market should not replace existing private markets, which experience suggests generally produce innovation much more efficiently. In other words, perhaps DARPA is a solution in search of a problem. Caution is in order.[93]

But a narrower lesson can be drawn. Neither defense procurement generally nor DARPA in particular are scalable. So they should not be implemented across the whole of government, all of the time. But maybe in rare moments of genuine crisis, such methods ought to be used. When the next worldwide pandemic hits a century from now, for example, maybe the DoD's crisis-mode type procurement methods should be employed. The temptation will be to label every problem a crisis, treating all types of procurement on par with weapons procurement. Two problems may arise. First, if everything is a crisis, then nothing is. Second, again, the government isn't very good at innovation. Devoting enormous public resources to research would displace private initiatives – hindering not helping innovation. OWS was modeled on DARPA, and it worked. But such solutions should be used sparingly.

V.- CONCLUSIONS

Just as we are thankful to the private-sector researchers who brought lifesaving coronavirus vaccines in record time, DARPA also deserves our praise. It funded key research into mRNA vaccines starting in 2010, whose breakthroughs were later critical to the rapid production of mRNA-based vaccines in 2020. It also served as a model for OWS. Yet enthusiasm about scaling DARPA across the whole of government or even around the world should be tempered by what we know about industrial policies. Experience suggests they do not work.

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[93] When the author presented this article to the aforementioned conference, Professor Valcárcel Fernández raised an important question. She asked whether public-private partnerships were the solution to the problems with government-sponsored innovation. The author's short answer was no. Embarrassingly, his limitations with the language prevented him from providing an extemporaneous answer that was fully responsive. However, as he has argued elsewhere, public-private partnerships are effective mainly for purchasing goods and services involving technologies that are stable and proven, not for developing innovation at the frontier of technology. See SCHOENI, D.; "Whither Innovation?: Why Open Systems Architecture May Deliver on the False Promise of Public-Private Partnerships", *Administrative Law Review*, volume 70, n° 2, 2018, pp. 443-48.

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