The Digital Age Produces Binary Outcomes

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The digital age produces binary outcomes. Winners tend to win overwhelmingly—in war as well as in business. The Soviet Union crumbled in the late 1980s when American technology bested Soviet military spending, then estimated at a quarter of GDP. The enormous Russian bet on military power lost and Communism fell. America emerged from the Cold War with a degree of military superiority greater than any country in modern history. It also emerged with a technologically driven economy that had no real competitor, with Russia close to ruin after the collapse of Communism and China in an early stage of economic development.

We have since come to consider American technological dominance a natural feature of the global landscape. That is a potentially fatal error. The military balance between the West and the Soviet Union shifted several times during the Cold War until the digital revolution gave the United States a definitive edge. But America achieved technological supremacy only because its leaders acted with a sense of urgency and responded to Russian advances by mobilizing America's resources on a grand scale.

Military strength and economic strength often rely upon the same policy foundations. The military and aerospace initiatives that won the Cold War also gave American companies a significant lead in the development of high technologies. That advantage has diminished steadily in the years since the fall of Communism, however. Without aggressive countermeasures, we risk losing it entirely.

We need to play catch-up in numerous fields. But the most glaring deficiency of the current policy approach is the decline of federal R&D spending relative to GDP. The policy initiatives that succeeded so brilliantly during the Cold War should provide a template for policymakers today. Renewing and improving defense R&D programs are not only essential to national security but can also become a critical driver of innovation and economic growth.

The Role of Technology in Winning the Cold War

Although the American victory in the Cold War was decisive when it ultimately came, that does not mean that it was easy, let alone foreordained. Different policies might have spelled defeat. The Soviet Union sent the first satellite into space in 1957 and the first man into space in 1961. If the Eisenhower administration had not responded to Sputnik with massive funding for basic research and scientific education, or if John F. Kennedy had not proposed the moon shot after Yuri Gargarin's first flight into space, or if public funds had not been channeled into private research facilities to meet military needs, or if Ronald Reagan hadn't undertaken the Strategic Defense Initiative—we would be living in a different world.

During the 1970s, military analysts calculated rates of attrition of tanks and aircraft to determine who was likely to win a war. At the time, they reckoned that Russia would beat the West in a war of attrition, and conventional wisdom called for détente as a way of delaying an inevitable

Soviet victory. Russian surface-to-air missiles and artillery as well as guided anti-tank weapons gave the advantage to Soviet-aligned Egypt in the largest air and tank battle since World War II, the 1973 Yom Kippur War between Israel and its neighbors. As Deputy Secretary of Defense Bob Work said in a September 2016 speech:

> In 1973 the Yom Kippur War provided dramatic evidence of advances in surface-to-air missiles, and Israel's most advanced fighters … lost their superiority for at least three days due to a SAM belt. And Israeli armored forces were savaged by antitank guided munitions. U.S. analysts cranked their little models and extrapolated that the balloon went up in Europe's central front and we had suffered attrition rates comparable to the Israelis. U.S. tactical air power would be destroyed within seventeen days, and NATO would literally run out of tanks.

Calculating men concluded that Russia would win an air and land war with the United States in Europe, which meant that Russia had the upper hand in the Cold War.

Then came the militarization of the microchip. During the Syrian collapse in June 1982, Israel deployed a combination of American and locally developed weapons systems and technologies, many in their first combat use, including F-15s and F-16s, AWACs,[1] lookdown radar, and remotely piloted vehicles. Decoy drones drew fire from the Soviet-made SAM batteries while Israeli fighters destroyed 17 out of the Syrians' 19 batteries. Superior command and control through faster computation and lookdown radar allowed Israeli F-4s, F-15s, and F-16s to destroy nearly 100 Syrian planes over the Bekaa Valley while losing just one Israeli fighter.

Such a victory would have been impossible without the new fast and light microchips that enabled the American-made fighters to carry sufficient onboard computing capacity for the new radar systems. The CMOS chips that powered the F-15's lookdown radar (beginning in 1978) were manufactured for the first time only ten years earlier, and for entirely different reasons. Originally the Defense Advanced Research Projects Agency (DARPA) commissioned RCA researchers to manufacture fast and light chips for weather analysis. In fact, the definitive inventions of late twentieth century technology—laser-powered optical networks, fast and light integrated circuits, and the Internet—all came out of Defense Department projects whose originators could not have foreseen the impact of the new discoveries.

The "Bekaa Valley Turkey Shoot" of 1982, as it came to be called, marked a decisive shift in the Cold War. In less than a decade, the American military (with some contributions from Israel) reversed what had appeared to be a decisive Soviet advantage in air combat and established overwhelming American superiority. By 1984, as Deputy Secretary Work commented, "Soviet Marshall Ogarkov famously said that reconnaissance strike complexes, the Soviet and Russian term for battle networks, could achieve the same destructive effects as low-yield tactical nuclear weapons."[2] The Soviet military concluded that it could never catch up to American avionics. That and the threat of the Strategic Defense Initiative persuaded Russia's leaders that America would win a conventional war, which set in motion the collapse of Communism.

Despite the overall weakness of President Jimmy Carter's foreign policy, the Defense Department under Secretary Harold Brown achieved many of the technological breakthroughs that helped the Reagan administration win the Cold War during the 1980s. In collaboration with the national laboratories and several major corporate laboratories, DARPA made a revolution in war-fighting that for the first time brought massive computing power to bear in a practical way. All the elements of the modern digital economy—integrated circuits, laser-powered optical networks, sensors, and displays—were invented at the behest of NASA or the Defense Department.

The director of RCA Labs who supervised their manufacture, Dr. Henry Kressel, and this writer described the impact of military-driven research and development in a 2013 article in the *American Interest*:

> When DARPA set out to create a communications system with multiple pathways for national security reasons, no-one had the slightest notion that this would create the Internet. When the Defense Department contracted RCA Labs in the 1970s to develop ways to illuminate night-time battlefields, no-one could have foreseen that the semiconductor laser would revolutionize telecommunications. And when the Defense Department commissioned RCA Labs to develop light and energy-efficient information processors to analyze weather data in the cockpits of military aircraft, no-one expected that the outcome would be mass production of inexpensive chips by the CMOS method.[3]

Kressel added:

> Companion technologies also sprang up that greatly expanded the ways in which lasers could be used. This led to their current status as not only the key to all fiber optic communication systems, including voice and data

> networks, but as the enabling technology of millions of instruments, DVD players, and a host of other devices.

Not one of the war-winning technologies funded by DARPA was employed for the purposes first envisioned by the Defense Department. And no one in DARPA or the laboratories developing these technologies foresaw their transformative impact on the civilian economy. Private entrepreneurs adapted the technologies that arose from defense research with remarkable speed. CMOS chip manufacturing was invented in 1963 at Fairchild Semiconductors, and the first CMOS chips were made at RCA Labs in 1968 under contract from DARPA. The first practical personal computers were on the market by the mid-1970s, and, by the 1980s, the personal computing revolution was in full swing.

American technological advances gave America an unequalled edge in military as well as civilian technologies, and America dominated world economic life to a degree not achieved since the highpoint of the British Empire during the nineteenth century. Fast and cheap computing, optical data transmission, sensing, imaging, CAD/CAM manufacturing—all the technologies that have defined the economy of the past thirty years—were products of America's drive to win the Cold War.

New Challenges to American Technological Superiority

Conservative critics frequently compare the Obama administration to the Carter presidency by arguing that the United States experienced a decline in world influence under both presidents.[4] In terms of defense fundamentals, however, the Obama presidency was incomparably worse. America's edge in defense technology has eroded and even fallen behind its prospective adversaries in critical areas. Federal research and development spending has dropped to barely half of its 1978 level as a proportion of GDP. The national laboratories are hollowed out, and the major corporate laboratories (at IBM, the Bell System, General Electric, and RCA among others) that contributed significantly to defense R&D during the Cold War no longer exist. Within the shrinking defense R&D budget, a disproportionate share has been squandered on the F-35, a poorly conceived and executed weapons system with the highest price tag in defense history.

FEDERAL R&D SPENDING AS % OF GDP

Source: National Science Foundation.

America remains the world's strongest military power, but select Russian and Chinese advances already limit America's strategic freedom of action. Russia's S-400 air defense system, for example, can acquire one hundred separate targets at distances of up to 400 kilometers. The deployment of the S-400 in Syria, moreover, made short work of American proposals for a no-fly zone in that country. U.S. commanders are not willing to risk stealth aircraft within the range of the S-400 because we do not know how close the Russians are to defeating stealth. The consensus view is that Russia cannot defeat stealth yet, but they may be able to do so in the not too distant future.[5]

Russia has already agreed to sell the system to China, which means that China could sweep the skies above Taiwan. China has two weapons systems that may be able to sink American aircraft carriers, the Dong Feng 21 surface-to-ship missile and the Type 039A diesel electric submarine, which is now virtually undetectable when running on battery power. Whether it wants to or not, America cannot deny China access to the artificial islands it is constructing in the South China Sea. It may be in no position to defend Taiwan.

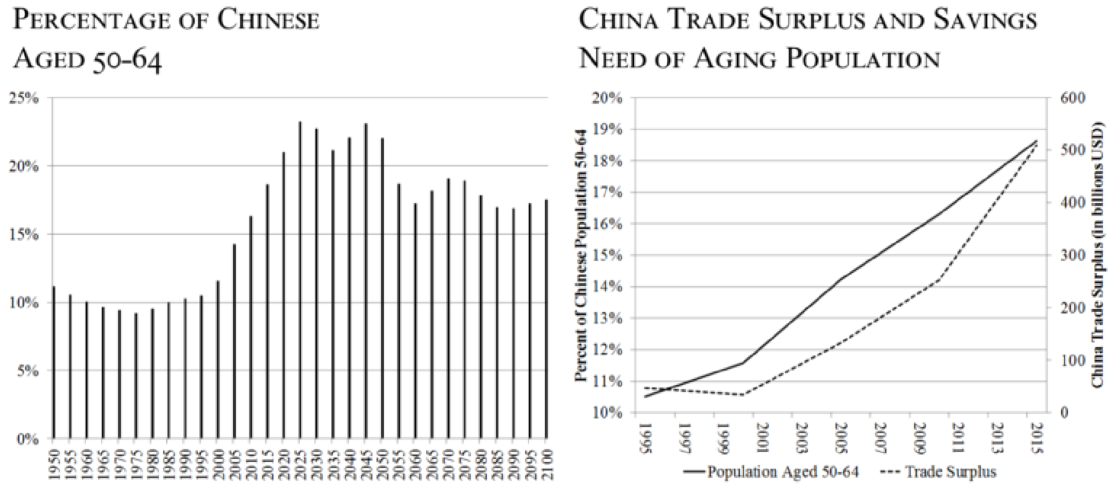
Many military breakthroughs—such as Israel's Iron Dome missile defense system—depend on the quality of algorithms and the speed of computation rather than on changes in hardware. Defeating stealth is mainly a matter of computation (enhancing a small radar footprint quickly enough to acquire a target). At present, China has the world's fastest and second-fastest supercomputers, made entirely with domestically produced integrated circuits.[6]

Although China's military industry in many respects remains a generation or more behind its U.S. counterparts, China has made advances in technologies that represent a strategic threat to the West to which the United States has no obvious countermeasures. These developments include satellite-killer missiles and hypersonic weapons delivery vehicles.[7] China has also ventured into experimental areas ahead of the United States in some key fields. Professor Michael Raska reported on China's launch of the world's first experimental quantum satellite, Micius, in December 2016: "While the Quantum Science Satellite will advance research on 'quantum internet'—i.e. secure communications and a distributed computational power that greatly exceeds that of the classical internet, Micius' experiments will also advance quantum cryptography, communications systems, and cyber capabilities that the China's military requires for its sensors and future strike systems."[8]

There is no single, decisive, dramatic breakthrough in China comparable to Russia's 1957 launch of the first orbital satellite or the first manned space flight in 1961. Instead, there has been a steady accretion of technological advantages that, combined, pose a threat to American strategic superiority over a ten- to twenty-year horizon. It is important to understand how touch-and-go America's position was at many junctures of the Cold War and the determination and commitment of resources that were required to restore America's technological advantage at moments when it was in jeopardy.

The Real Chinese Threat

The way to lose the next war is to fight the last war. China's trade surplus looms large as a challenge to American prosperity. For reasons that have nothing to do with American policy options, China's trade surplus is likely to diminish gradually over the next ten years. The Nobel Prize–winning Professor Robert Mundell, the father of supply-side economics, showed (along with other economists) that chronic trade imbalances stem from demographic shifts. Old people lend to young people, and countries with aging populations lend to countries with younger populations. They acquire the savings to be lent by running current account surpluses.[9]

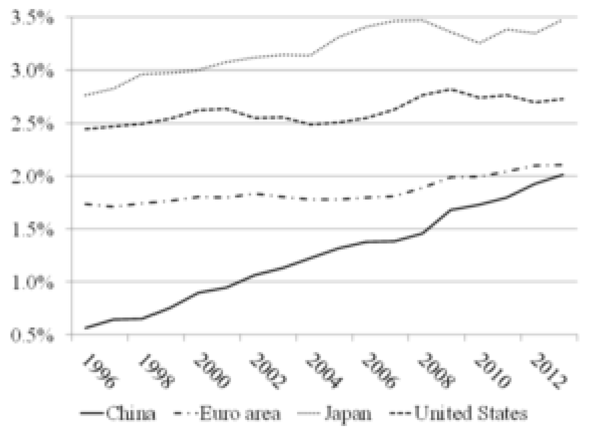


China's enormous trade surpluses coincided with the rapid aging of its population.
Sources: United Nations Population Prospects, St. Louis Federal Reserve FRED database.

A proxy of national demand for savings is the percentage of the population approaching retirement age. In China's case, the demographic cohort aged 50 to 65 years will double between 1995 and 2020. After 2020, China's rate of aging and demand for savings will level off.

As China's demand for savings tapers off during the next decade, its trade surplus should gradually fall. This trend is consistent with Chinese policy, which seeks to shift the economy away from dependence on exports to domestic consumption—that is, to increase consumption and reduce savings. This shift is perhaps the most commented-upon policy change in the world economy today.

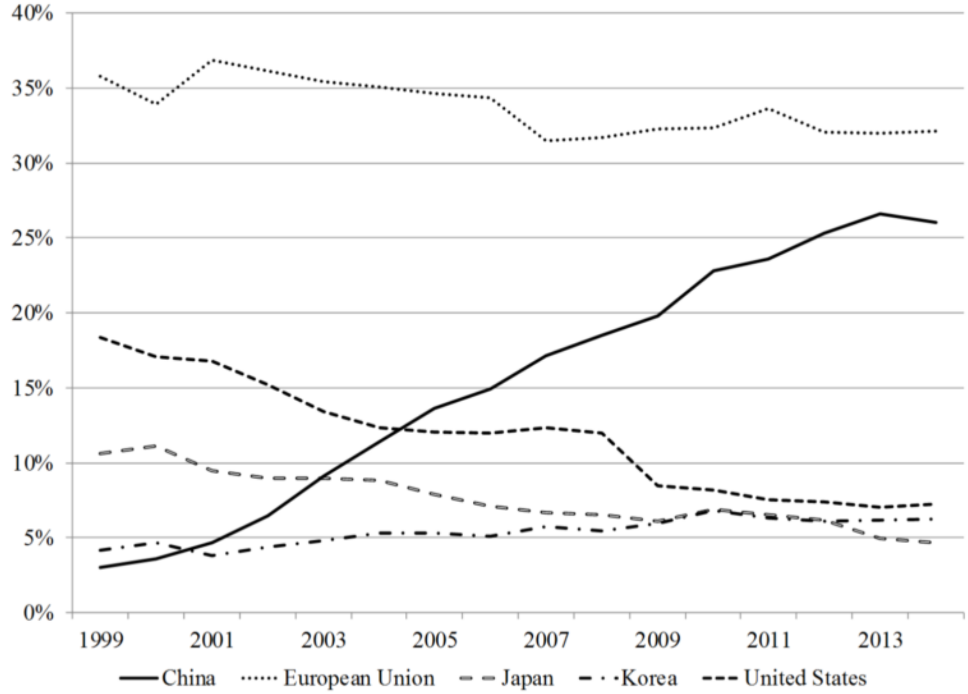
R&D AS % OF GDP



Source: World Bank.

Higher consumption implies a lower trade surplus. But that, unfortunately, is not the end of China's economic challenge to the United States. On the contrary: that is where China's challenge to the United States will begin in earnest. Going forward the issue will not be the quantity of Chinese exports but their quality. The old caricature of the Chinese economy of a cheap-labor, pollution-spewing throwback dependent on stolen technology contained a good deal of truth a decade ago. But a radical transformation is already underway that has led to Chinese dominance in high-tech exports, as defined by the World Bank. In 1999, China's share of global high tech exports was only 3%. In 2016 its global share rose to 26%. America's share fell from over 18% to just 7%. China's R&D spending has already reached the level of Europe as a percent of GDP.

SHARE OF GLOBAL HIGH TECHNOLOGY EXPORTS



Source: World Bank.

High-tech industrial production has been shifting away from the United States since the late 1990s. Until then, America ran a substantial surplus in high-tech goods. In the early 2000s, however, that surplus turned into a deficit, which is likely to exceed $100 billion this year.

Most of America's trade deficit in high-tech goods consists of technologies invented in the United States, often supported by federally funded research sponsored by the Department of Defense and NASA. The seven technologies listed below constitute the basic elements of all modern electronics from computers to smart phones; in each case, their manufacture has migrated to Asia because Asian governments adopted the formerly American practice of supporting basic R&D. The economic benefits of the digital revolution that originated in the United States have shifted to Asia. America's share in the manufacture and distribution of its own inventions is relatively small.

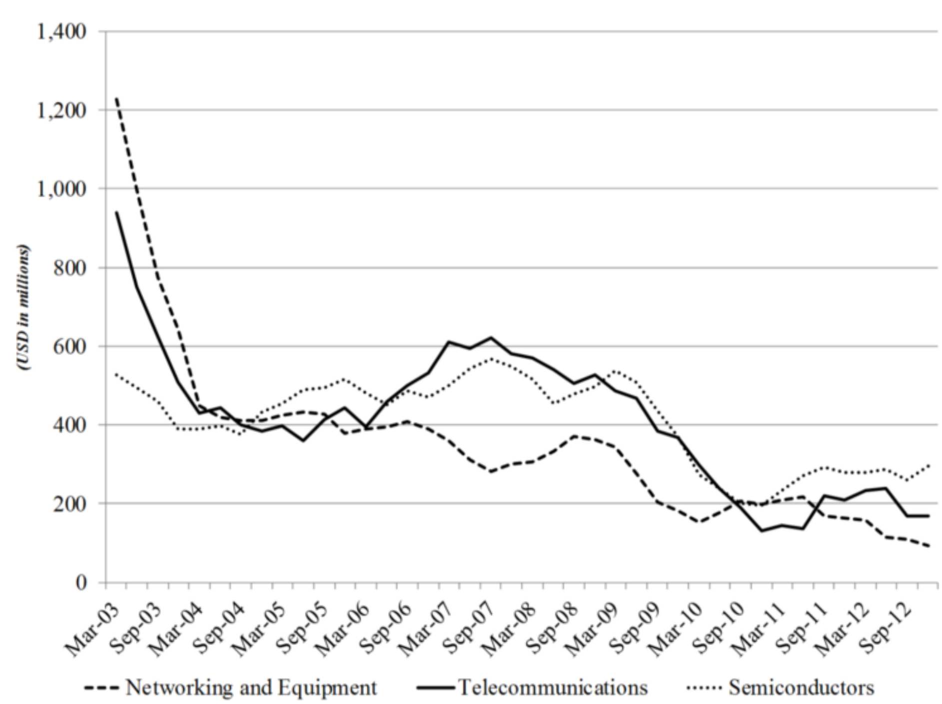
The core digital technologies include the following:

1. Liquid crystal displays, which are employed in a wide variety of products, with $100 billion in annual sales. South Korea controls 35% of the market, Taiwan 25%, and China 20%.
2. Light-emitting diodes (LEDs) are produced mainly in China and Taiwan.
3. China and Taiwan dominate the production of semiconductor lasers, the energy source for fiber optic communications.
4. Solid state sensors, which generate images in digital cameras and related devices, are produced mainly in Taiwan and Japan.
5. Flash memory is produced mainly in South Korea, Japan and China, with only 10% of world output coming from the United States.
6. Integrated circuits are a $270 billion global industry. Most are produced in Taiwan and South Korea, and China has undertaken an aggressive investment program in the industry. Less than a quarter of world output is produced in the United States.
7. Solar energy panels, a $30 billion industry, are dominated by China.

Venture capital commitments to the manufacturing industry have collapsed because American investors do not believe that American industry can stand up to Asian competition. Some of the Asian advantage is the result of the theft of intellectual property, but most of it stems from above-board collaboration of government and industry. Asian countries have licensed U.S. technologies and supported joint ventures with American companies in order to foster technology transfer, and they have made cheap capital available to their high-tech industry. Asian governments also have supported technical education. China now graduates twice as many STEM Ph.D. candidates as the United States does each year.

America developed many of the high technology products that are built by Asian manufacturing. But Asian dependence on American technology is starting to diminish. China's flagship high-tech manufacturer, Huawei, now employs tens of thousands of engineers, including thousands of Western researchers in several centers in Europe. A decade ago Huawei was regularly accused of stealing Western technology; now it is a vigorous defender of intellectual property rights, because it is heavily committed to innovation of its own. Huawei now spends 14% percent of gross revenues on R&D, more than Microsoft and the same level as Google.[10]

Venture Capital Investments in Manufacturing



Source: National Venture Capital Association

A New R&D Policy Agenda

Is it too late for American high-tech manufacturing? No, but drastic policy changes are required. Tax incentives for exports and tax disincentives for imports may not be sufficient to turn the tide of Asian dominance. In many instances, the entire supply chain for tech projects has relocated to Asia, which leaves American manufacturers overwhelmingly dependent on Asian production for imports. The simplest and most direct response would be to require domestic production for all sensitive defense-related goods, including all computers, displays, integrated circuits, sensors, and other high-technology equipment used in defense applications. In other words, for certain important categories of security-related manufactures, the tariff should be infinite. This is the only reliable way to ensure that American manufacturers will bring production, including critical parts of the supply chain, back to the United States.

Russia's head start in the space race elicited a national effort to keep American technology in the forefront in the late 1950s and early 1960s. The very real possibility that Russia might triumph in the Cold War motivated a comparable effort in the early 1980s. We need the same sense of urgency today. We have no guarantees that America will retain technological leadership. Britain dominated world industrial production in 1870 with a third of total global output, but fell to a seventh of the world total by World War I. In 2010 China edged out the United States to become the world's largest goods producer, with a fifth of the global total.

Russian and Chinese advances in air defense, missile technology, submarine warfare, satellite interdiction and other critical areas pose a set of scientific problems comparable to the ones that DARPA addressed during the 1960s through the 1980s. Targets for future scientific research should include (but of course are not limited to):

1. Defeating the current generation of Russian air defense systems
2. Enhanced use of drones in place of manned aircraft
3. Hardening of satellites against prospective enemy attack
4. Cyber warfare
5. New physical principles in computing (e.g., quantum computing)
6. Quantum communications and encryption
7. Detection of ultra-quiet submarines (the present generation of Chinese diesel-electric boats are practically undetectable, and submarine drones could be used to deliver nuclear weapons to coastal cities)
8. Detection and defeat of the next generation of hypersonic missiles
9. Countermeasures against anti-ship missiles (rail guns, laser cannon)

America succeeded in the Cold War because of "long ball" rather than "small ball" research and development. Corporate R&D usually must be justified by relatively short-term improvements in revenues. Investigation of new physical principles cannot typically be justified by corporate planners. That is why military R&D plays such a unique role; to win wars, the United States has had no choice but to push the envelope of physical knowledge.

Federal R&D Spending and Productivity Growth

By one measure, the growth rate of labor productivity, the American economy is in its worst shape since the stagflation of the 1970s, and there is a close relationship between federal R&D spending and productivity growth. The chart below shows the annualized growth in productivity over five-year intervals against the annualized change in federal R&D spending. It is noteworthy that productivity growth tracks federal rather than overall R&D spending. That is because research that leads to fundamental breakthroughs is more likely to be funded for defense and aerospace needs. "Long ball" R&D typically involves strategic objectives, while private R&D focuses on "small ball" requirements with specific product goals in sight. In many cases, federal R&D has led to innovations with enormous economic consequences that were completely unforeseen by the original sponsors; this is the nature of frontier research.

The notion that defense and aerospace R&D fosters economic growth is not new. In 1976 NASA released a study by Chase Econometrics stating that if a "sustained increase in NASA spending of $1 billion (1958 dollars) for the 1975–1984 period" were implemented, then "constant-dollar CNP would be $23 billion higher by 1984," versus a baseline of no increase in expenditures.[11] Even so, conventional methods of economic estimation cannot begin to assess the revolutionary impact of breakthrough technologies on American productivity, because these technologies radically changed what economists call the investment opportunity set—the basic constituents of the economy itself. The civilian use of these defense technologies vastly outstripped the original objectives of their government sponsors. The demands of American defense pushed scientists to discover new physical processes, among them solid-state semiconductors, and these discoveries transformed economic life.

The challenges to American growth and productivity today are arguably even greater than they were when Jimmy Carter left office in 1981. Consider the following:

1. America's population is aging rapidly: 15% of the total population will be 65 or older in 2015, rising to 20% by 2030.
2. America had little foreign competition as a venue for entrepreneurial startups in the 1980s: the world's capital and talent had nowhere to go but the United States. Now there are numerous competing venues for technological entrepreneurship.
3. Several rising Asian powers, particularly China, have acted aggressively to close the technology gap with the United States, and they have leapfrogged American manufacturing in a number of key industries.
4. Federal debt was only 30% of GDP in 1979 (not counting unfunded entitlements) but rose to 110% in 2015.
5. Obstacles to growth at the end of the Carter administration—a 70% top marginal tax rate and an inflationary monetary policy—were easier to identify and remedy than contemporary challenges.
6. America's backlog of productivity-enhancing technologies has shrunk, in large part because defense R&D is half of what is was in the late 1970s relative to GDP.

Economic growth depends on technological innovations, and entrepreneurs who take risks to commercialize them. Absent innovation, entrepreneurs will find other things to do, such as designing new financial derivatives. But technological innovation will have as little impact as gunpowder and the movable type had on the medieval Chinese economy unless entrepreneurs plunge into the chaotic, disruptive work of commercializing these technologies.

Creating Unintended Consequences

Federal R&D is effective not merely because it is federal, however. On the contrary, governments frequently waste R&D funds on white elephant projects such as Solyndra, the California-based solar power venture that defaulted on a $535 million U.S. government loan. The F-35 and other poorly conceived acquisition programs also absorb large amounts of R&D funding. In contrast to these incremental projects, R&D that is focused on game-changing breakthroughs is the most productive. And the technological innovation it makes possible becomes truly transformative only when entrepreneurs effectively commercialize it. Kennedy's moon shot and Reagan's Strategic Defense Initiative had such lasting economic reverberations because they were accompanied by tax cuts and regulatory relief that made it easier for entrepreneurs to capitalize on basic scientific innovations. The Trump administration has already proposed aggressive fiscal and regulatory measures to improve incentives for investment. Neither innovation nor investment alone is enough, however; the innovations must turn into investment and employment in the United States.

PRODUCTIVITY VERSUS DEFENSE R&D SPENDING (5-YEAR CHANGE)

Sources: Commerce Department Bureau of Economic Analysis, National Science Foundation.

There is a clear division of labor between the public sector and the private sector. Few if any of the game-changing inventions of the 1950s through the 1980s would have emerged—or emerged as early as they did—without federal R&D funding. Once the technology is invented, though, private investors must bear the brunt of the risk. Conventional industrial policy is the worst approach. It allows bureaucrats to create vested interests in existing industries, and it creates incentives to suppress new technologies that might threaten investments undertaken by political cronies. There is a strong case, however, for using government funds to seed new companies that can develop innovative technologies. In an ideal world, the venture capital community would assume this function. But in the real world, the requirements of defense R&D and production require public funding.

The unintended consequences of federally sponsored R&D vastly exceeded the expectations of the projects' initiators. The economic spinoffs of the technologies invented for urgent national security reasons had incalculable impacts on growth and productivity. None of this could have been pre-programmed. Innovation is unpredictable by definition. The greatest lesson we can draw from both the Kennedy space program and the Reagan Strategic Defense Initiative is that the most productive investments are the ones that test the frontiers of physics. These projects enabled us to fight the next war, not the previous one.

Unlike the Russian space flights of 1957 and 1961, or the success of Russian air defenses in the Yom Kippur War, we can point to no single development to provoke a "Sputnik moment." Like a frog in a pot of cold water, we do not notice the gradual increase in temperature. Circumstances nonetheless demand a sense of urgency comparable to that experienced at the peak of the Cold War. We can leapfrog our competitors. Or we may suffer the fate of a boiled frog.

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Notes

[1] Stephen Bryen, with Rebecca Abrahams and Shoshana Bryan, *Essays in Technology, Security and Strategy* (N.p.: Amazon, 2015), 46.

[2] Bob Work, "Remarks to the Air Force Association," Sept. 21, 2016, https://www.defense.gov/News/Speeches/Speech-View/Article/973907/remarks-to-the-air-force-association.

[3] David P. Goldman and Henry Kressel, "Prosperity, Security and Markets," *American Interest*, Oct. 10, 2013, http://www.the-american-interest.com/2013/10/10/prosperity-security-and-markets/.

[4] See for example Conrad Black, "How the U.S. Lost the World's Respect," *National Review*, May 27, 2015, http://www.nationalreview.com/article/418855/obamas-mideast-morass-conrad-black. See also Jed Babbin, "Competing for the 'Worst Former President,'" *Washington Times*, Dec. 4, 2016, http://www.washingtontimes.com/news/2016/dec/4/obama-competing-with-jimmy-carter-for-worst-former/.

[5] See Dave Majumdar, "America's F-22 and F-35 Stealth Fighters vs. Russia's S-300, S-400 and S-500: Who Wins?," *National Interest*, Aug. 18, 2006, http://nationalinterest.org/blog/the-buzz/americas-f-22-f-35-stealth-fighters-vs-russias-s-300-s-400-s-17394.

[6] See Patrick Thibodeau, "China Builds World's Fastest Supercomputer without U.S. Chips," *ComputerWorld*, June 20, 2016, http://www.computerworld.com/article/3085483/high-performance-computing/china-builds-world-s-fastest-supercomputer-without-u-s-chips.html.

[7] See Office of the Secretary of Defense, "Annual Report to Congress: Military and Security Developments Involving the People's Republic of China 2015," https://www.defense.gov/Portals/1/Documents/pubs/2015_China_Military_Powe

[9] See Robert Mundell, "The International Distribution of Saving: Past and Future," in *World Saving, Prosperity and Growth*, ed. Mario Baldassarri, Luigi Paganetto, and Edmund S. Phelps (New York: St. Martin's, 1993), 5–56.

[10] See "Huawei Reports Revenue of CNY395 Billion in 2015," April 1, 2016, http://www.huawei.com/en/news/2016/3/huawei-reports-revenue-of-cny395billion-in2015.

[11] Michael K. Evans (Chase Econometrics), "The Economic Impact of NASA R&D Spending," April 1976, https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19760017002.pdf.