Establishing a Globally Leading Science and Technology Innovation System: The Path of the United States to Becoming a World Science and Technology Power (Postprint)

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Abstract

From the perspective of the origin and development of the national innovation system, this paper examines the developmental trajectory and critical junctures of the United States' emergence as a world leader in science and technology. It identifies that during its evolution into a global scientific and technological powerhouse, the United States established, following World War II, an innovation system characterized by a tripartite partnership among government, universities, and industry, which catalyzed the rapid advancement of American science and technology. Simultaneously, the development of American science and technology has also been driven by responses to external challenges and the pursuit of transformative change. The paper contends that the spirit of scientific freedom and autonomy, the integration of basic research with applications, a diversified investment framework, and an innovative cultural milieu constitute pivotal factors in America' s ascendance as a world science and technology powerhouse.

Full Text

Building a Globally Leading Science and Technology Innovation System—The U.S. Path to Becoming a World Science and Technology Power

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Abstract

From the perspective of the origin and development of the national innovation system, this paper examines the developmental path and key milestones that transformed the United States into a world science and technology power. It argues that through a long historical process, and particularly after World War II, the United States formed an innovation system characterized by a partnership among government, universities, and enterprise, which propelled the rapid advancement of American science and technology. Simultaneously, U.S. science and technology have continuously developed through responsive transformations to external challenges. The paper identifies scientific freedom and autonomy, the integration of basic research with applications, a pluralistic investment system, and an innovation-oriented cultural environment as the foundational elements that established America as a world science and technology power.

Keywords: world science and technology power; American science and technology; innovation system; scientific freedom and autonomy

Introduction

After World War II, the United States emerged not only as the world' s leading military and economic power but also as its foremost scientific and technological power. America has consistently held a preeminent position in basic science while inventing and developing numerous high technologies that have shaped both national and global progress. Moreover, American universities have become centers of world science and education, continuously attracting young scholars from around the globe for advanced studies. Why did the United States become the world' s most powerful nation in science and technology after WWII, and how has it maintained this leadership? While the influx of European scientists before and during WWII, and later the arrival of scientific talent from across the world, certainly contributed significantly, perhaps more crucial was the postwar establishment of an organizational system and research environment that incentivized innovation, enabling the full expression of talent and capability across all sectors and thereby driving continuous scientific and technological advancement. This phenomenon warrants multi-faceted investigation. Previous analyses have examined this transformation from historical roots, government policy, and bounded change perspectives [**?**]. This paper focuses primarily on the origin and evolution of the innovation system to explore the American path to becoming a world science and technology power, its key developmental events and turning points, and its successful experiences.

Pre-WWII Development: Learning, Catching Up, and Self-Reliance

From its founding through the pre-WWII period, American science and technology followed a trajectory of learning, catching up, and achieving self-reliance. By the eve of WWII, the United States had already caught up with European advanced nations across many scientific and technological fields and had established a system promoting scientific and technological innovation, laying the foundation for postwar development.

Formation of the American Scientific Community

Science in the North American colonies originated from Europe and grew through continuous exchange with European science. From American independence through the end of the Civil War (1776–1865), American science began to achieve independence from European—particularly British—scientific traditions, though still on a modest scale. The three decades following the end of the War of 1812 marked the beginning of American science, during which practitioners transformed from a dispersed group of amateurs without common goals into a professional community, establishing numerous societies and journals. The founding of the American Association for the Advancement of Science (AAAS) in 1848 signaled the formation of the American scientific community [?], while the establishment of the National Academy of Sciences (NAS) in 1863 created an elite body of scientists tasked with providing scientific advice to the government.

Government scientific activities played a major role in the professionalization of American research. Although the U.S. Constitution did not explicitly mandate support for science, it implicitly authorized federal support within various applied contexts. Consequently, the federal government supported science as an adjunct to achieving national and social development goals, including defense, resource surveys, agriculture, and health. Beginning in the 19th century, the government established its first scientific agencies with applied objectives, such as the Coast Survey in 1807 and the Naval Observatory in 1842. The creation of the Department of Agriculture in 1862 marked a new height in federal support for scientific research within government agencies. These institutions employed the first generation of professional scientists, some of whom simultaneously served as leaders and backbone members of scientific societies, guiding the nation' s scientific development.

Rise of American Research Universities and Scientific Research

Most early American universities were established to meet local practical needs, though a few like Harvard (1636) and Yale (1701) were modeled on traditional British institutions. Public universities (state universities) began developing in the early 19th century, and science gained prominence in higher education from the mid-19th century onward. The Morrill Act of 1862 established landgrant colleges to promote state university development. However, American universities remained relatively backward through the mid-19th century, with young Americans traveling to Europe, particularly Germany, for doctoral studies. Upon their return, they brought back the German model integrating research and education—such as seminars featuring equal discussion between faculty and students—and adapted it to American conditions, fostering university development including the founding of new institutions (e.g., Johns Hopkins University, University of Chicago) and the revitalization of older ones.

By the 1870s, many universities began encouraging faculty to pursue academic research and train students through research, fully demonstrating the educational value of inquiry and giving rise to American research universities. Simultaneously, science entered the core university curriculum, making universities "homes of science" and accelerating American scientific development in the late 19th century. By 1920, the modern form of American research universities had taken shape and achieved dominance in American higher education.

American universities developed distinctive characteristics. First, they constitute a highly decentralized competitive system dominated by private institutions. Unlike many European countries with central decision-making bodies (e.g., Ministries of Education) determining university policy, authority over American higher education resides with states rather than the federal government. Each state can manage university development according to its actual circumstances, emphasizing institutional autonomy. Within this autonomous, decentralized, and competitive system, scientists can freely choose research questions based on their own scientific judgment and reward peers for high-quality work, promoting both academic and scientific advancement [?]. Second, American universities emphasize practicality, actively responding to local economic and industrial development needs. University development has proceeded hand-in-hand with industrial growth, with both private university establishment and state support for public universities closely linked to regional development. In the first half of the 20th century, new engineering disciplines gradually became institutionalized within universities around emerging industries, strengthening the connection between universities and industrial development [?]. These characteristics enable American universities to respond more quickly and extensively to economic and social environmental changes.

By the late 19th and early 20th centuries, American scientific spirit increasingly emphasized indigenization and independence from European science. The 1907 Nobel Prize awarded to physicist Albert Michelson marked America' s achievement of scientific self-reliance.

Development of American Industrial Technology and Research

Britain pioneered the First Industrial Revolution, but America followed rapidly. By the first half of the 19th century, the United States had surpassed Britain in certain industrial sectors, such as instrumentation and equipment, while its railroads and transportation systems achieved tremendous development. In the latter half of the 19th century, America became world-renowned for inventions and innovations in producer and consumer goods. By the 1890s, American steel production and the efficiency of its production companies were globally recognized. Although most key discoveries and inventions were still made by Europeans, America had surpassed Europe in the practical application of science. By the start of World War I, the United States had achieved world leadership in mass production industries.

During the Second Industrial Revolution, dominated by chemistry and electrical engineering in the late 19th and early 20th centuries, America kept pace with Europe, establishing chemistry and electrical engineering departments in universities. By World War I, the American university system could effectively supply scientific and technical personnel for science-based industries. Although some of the most creative scientists in American industrial research laboratories before WWII were still trained in Europe, the majority were increasingly American-trained after 1920. Before WWI, America established its first classic industrial research laboratories in the electrical industry, conducting frontier scientific research. American electrical engineering achieved world leadership, developing in close connection with telegraph and electronics industries.

Between WWI and WWII, the American economy centered on the automobile industry, driving development in steel, glass, rubber, and petroleum industries and strengthening its leadership in mass production. In synthetic organic chemicals, chemical process instrumentation, and precision machinery, America was a strong European competitor. While early American chemical industry lagged significantly behind Germany, by the 1930s the United States had substantially closed this gap [**?**].

Summary of Pre-WWII American Science and Technology

Before WWII, the United States had established a science and technology innovation system centered on universities and industrial research laboratories, with government support concentrated in applied fields addressing national and social needs, particularly agriculture. Between 1930-1940, industrial research laboratories had become the mainstay of American innovation, with R&D funding distributed as follows: government 12%-19%, industry 63%-70%, and universities 9%-13% [**?**]. This market competition-based system responded flexibly to economic and social development needs, featured natural connections and ample mobility within the system, and emphasized bottom-up creativity, laying the foundation for subsequent greater development.

Conventional wisdom holds that Western Europe maintained clear scientific leadership until the 1930s, with America relying on European original innovations for application and development. However, sociologist Joseph Ben-David' s study of 50 major inventions in the first half of the 20th century suggests this view is at least partially incorrect—American basic science grew faster than Europe' s after 1920, and the United States not only applied European science but also demonstrated stronger capabilities than Europe in moving from original innovation to final products [?].

Transformation of Government-Science Relations During WWII

The Wartime Partnership Between Government and Science

World War II represented a watershed in American science and technology development. As authority on U.S. science policy Professor Harvey Brooks observed: "Among industrialized countries, the United States is the only one whose R&D system and science policy were permanently transformed by World War II" [?]. Before WWII, federal support for science was limited to application-oriented objectives within government agencies. During WWII, a fundamental policy shift occurred, making the federal government the primary supporter of national S&T development—a role that was established and continued after the war.

To meet wartime needs, America's plans to develop, deploy, and utilize advanced military technologies involved numerous scientific and technical sectors with participation from diverse institutions and scientists. The war' s scale and urgency necessitated new mechanisms to manage complex programs, accelerate R&D, coordinate new research forces, and integrate them with overall military development. During the war, these special mechanisms were controlled by a small group of scientific elites led by Vannevar Bush, who represented the interests of scientists across major sectors.

Assessing the war situation, Vannevar Bush firmly believed technology would play a crucial role in future American wars. Since warfare had become highly technological, it could not be left entirely under military control as in WWI. "The times called for the opposite: to let those familiar with the latest advances in science become familiar with the needs of the military, so they could tell the military what was scientifically possible, and thus together evaluate what should be done"[?]. Bush united scientific elites to petition the White House to mobilize scientific and technological resources. They envisioned an institution with its own funding, managed by civilian scientists, reporting directly to the president, independent of military departments and other government agencies yet coordinated with them. On June 12, 1940, President Roosevelt approved Bush' s proposal, establishing the National Defense Research Committee (NDRC). The NDRC' s creation inaugurated a new era in government-science relations. As science historian A. Hunter Dupree wrote in his seminal work *Science in the Federal Government*: "1940 marks the beginning of a new era in the relations between the federal government and science. Up to this point, one can draw a line on the road of historical continuity; this date separates 150 years of American experience in this field from subsequent experience. With a complete change in operational scale, science dramatically moved to center stage" [?].

A year later, the NDRC expanded into the Office of Scientific Research and Development (OSRD), with Vannevar Bush as director, directly responsible to the president and occupying a central position among federal agencies overseeing science. The OSRD became the "command center" for national scientific activities during the war. Its fundamental purpose was to keep scientific selection in scientists' hands, allowing them to independently judge the value of research directions. This organizational structure preserved scientific autonomy. Department leaders came from universities or other institutions and were granted extensive freedom in implementing policies [?]. Rather than exercising "central" control through administrative directives, the OSRD operated through contracts—a major innovation in science-government relations. This approach made academic institutions and industry partners of the federal government rather than entities under its direct control. From then on, the U.S. government shifted from supporting only its own research to supporting a much broader range of research nationwide through contracts.

Impact of the OSRD

Since its establishment, the OSRD achieved tremendous accomplishments, including early atomic bomb development, radar, radio proximity fuses for bombs, computers, mass production of penicillin, and DDT for military medicine. During WWII, the U.S. government became the primary funder of scientific research, with government R&D funding growing from $480 million in 1940 to $5 billion in 1945, increasing its share of total national R&D expenditure from 18% to 83% [?].

Through the NDRC and OSRD, America' s wartime mobilization created an innovation network linking government, universities, research institutions, industrial enterprises, and the military. Although wartime organizational forms were replaced after WWII, the network and interpersonal relationships formed during the war persisted, laying a remarkable foundation for the later complex and dynamic partnership among government (military departments), industry, and universities.

The OSRD trained an entire generation of science managers who shaped postwar U.S. science policy. Practices adopted during OSRD operations—respecting scientific autonomy, supporting the best science, and using contract systems—were accepted, developed (with contract systems later evolving into grants and other forms), and continued, forming the basis of postwar American science and technology policy.

Post-WWII Transformation of Federal Support for Science and Technology

The Federal Government' s Changing Role

The enormous contributions of scientists during WWII created widespread belief in science as a progressive force that could promote national prosperity, public health, and social advancement. Postwar concerns focused on how to maintain the scientific and technological capabilities formed during the war. In 1945, at President Roosevelt' s request, Vannevar Bush completed the report *Science—The Endless Frontier*, which portrayed science as a "new frontier" that would replace the physical frontier of the American West as a driver of economic development, improved living standards, and social progress. The report' s fundamental tenets were: (1) scientific progress is essential for ensuring public health, national security, and public welfare; (2) basic research is the source of all knowledge, and its development inevitably brings broad societal benefits; and (3) the scientific community needs relative autonomy and freedom of inquiry to avoid political and other interest group pressures, thereby ensuring scientific progress. Based on these principles, the report proposed that the federal government should assume responsibility for maintaining scientific knowledge advancement and cultivating new scientific talent, recommending the establishment of a National Research Foundation (the original name for the National Science Foundation)—a funding agency covering all natural science fields and including a department for long-term military research. Bush positioned universities as the center of postwar science policy implementation [?].

Bush' s report built upon the OSRD' s wartime successes. The concept that the federal government should assume primary responsibility for supporting science and technology reflected the consensus of American political and social circles at the time. The report embodied the idea of a "social contract for science": the government guarantees funding for basic research and scientific freedom, while scientists guarantee that their discoveries will bring broad benefits to society.

Postwar debates among various stakeholders with different views on science policy were intense. Ultimately, Bush' s vision of government-supported science prevailed—establishing the government as the primary funder of science. However, his specific organizational vision—a unified, national agency managed entirely by scientists, the National Research Foundation—did not materialize. Between 1945-1950, during five years of debate over the National Science Foundation' s establishment, and to fill the void left by OSRD' s dissolution, the Office of Naval Research, the Atomic Energy Commission (AEC, predecessor of the Department of Energy), and the National Institutes of Health (NIH) began supporting scientific research. The AEC not only supported university contract research but also created a series of national laboratories based on university-managed facilities. When the National Science Foundation (NSF) was finally established in 1950, it was merely one of many federal departments and agencies supporting scientific research, resulting in a pluralistic funding system.

Organizational Innovation in Federally Funded Research

Post-WWII, the U.S. federal government created and updated numerous organizations to support scientific research, each established and developed to fulfill specific missions. For example, the Atomic Energy Commission was created to research atomic energy utilization, the Office of Naval Research to support naval development, and the Advanced Research Projects Agency (ARPA) to conduct cutting-edge R&D for defense needs. Thus, America deployed and conducted scientific research according to national security, economic, and social development goals and needs. This mission-oriented research, conducted to achieve broad agency objectives, tightly integrated research with application domains, promoted mutual reinforcement between basic and applied research, and drove breakthrough scientific and technological progress. For instance, the Department of Energy' s long-term funding of research on radiation effects on biological organisms led to the launch of the Human Genome Project.

By the late 1970s, major U.S. departments and agencies supporting scientific research—including the Department of Defense, Department of Health and Human Services (primarily NIH), NASA, Department of Energy, Department of Agriculture, and NSF—were all established. Pluralism represents an advantage of the American research funding system: it provides researchers with diverse funding sources, introduces competition that compels agencies to improve management, and enables different agencies to fund research in the same technological field from different perspectives, effectively promoting mutual reinforcement and coordinated development. The evolution of U.S. information technology exemplifies this dynamic.

Confronting the "Sputnik" Challenge

On October 4, 1957, the Soviet Union launched Sputnik, the first artificial Earth satellite, demonstrating Soviet leadership in rocket and intercontinental ballistic missile technology. This event caused tremendous shock in the United States, prompting rapid mobilization of national resources to counter the Soviet threat. Between late 1957 and 1958, within a single year, the U.S. established the National Aeronautics and Space Administration (NASA) to formulate and implement national space development plans; the Department of Defense created the Advanced Research Projects Agency (ARPA, renamed DARPA in 1972) to ensure advanced technology R&D for military needs and unexpected technological breakthroughs; the President' s Science Advisory Committee was formed to strengthen governmental scientific decision-making; new weapons development was intensified; and the National Defense Education Act passed by Congress in November 1958 greatly strengthened federal support for science education at all levels. On January 31, 1958, the United States successfully launched its own artificial satellite.

The decade following Sputnik' s launch represented a "golden age" in modern American science and technology history, during which the United States became the world leader in science and technology. During this period, U.S. R&D funding grew at an average annual rate of 15%, often exceeding GDP growth rates. Between 1957-1967, federal research expenditures nearly quadrupled, reaching $15 billion. Non-defense research began occupying a larger share of total federal R&D funding, particularly in space science and medicine. Basic research funding from all supporting agencies increased substantially, reaching 14% of total federal funding by 1967, with the NSF' s budget reaching $500 million, accounting for 13% of federal funding for university basic research. The United States produced 6,000 science and engineering doctorates in 1960, increasing to over 18,000 by 1971. American science and technology achievements accumulated rapidly, including 38 Nobel Prize winners [?]. The U.S. S&T system produced not only nuclear weapons and intercontinental missiles but also jet aircraft, computers, semiconductors, nuclear energy, lasers, satellite communications, microwave communications, countless consumer products, and medical breakthroughs. America became the origin and leader of modern high technology.

Development of U.S. High Technology and the National Innovation System

The Information Technology Revolution

American high technology that developed spectacularly after WWII—including computers, semiconductors, and later the internet, biotechnology, and medicine—has become a new source of American advantage with lasting impact. The development of U.S. high technology represents a multi-level, multi-angle, intersecting historical narrative that evolved within a dynamic innovation system comprising government support, university research, startup companies, private R&D investments by established corporations, and related institutions and policies (such as defense-related R&D and procurement, antitrust policies).

The representative American high technology is information technology—the sum of computer, semiconductor, and communication technologies. Initially developing independently in the mid-20th century, these technologies became increasingly interconnected from the 1960s onward, forming a complex system that brought about a technological revolution. At different developmental stages, breakthroughs and advances in these fields were brought about to varying degrees by interactions among government, universities, and enterprises.

(1) Computers. During WWII, both Britain and the United States began supporting computer development for military objectives. In November 1945, the world' s first electronic digital computer, ENIAC, was born at the University of Pennsylvania. Postwar, the U.S. federal government not only funded most early digital computer development but also continued supporting breakthroughs across a broad range including time-sharing, artificial intelligence, and virtual reality. Federal investment also provided essential physical infrastructure support for computer science graduate education. Computer science and technology developed with federal funding were later matured by private enterprises.

(2) Semiconductor Technology. Unlike computers, semiconductor technology originated from private sector-led development. In 1947, AT&T' s Bell Laboratories invented the transistor, enabling key developments in semiconductor technology and establishing the American semiconductor industry. All major breakthroughs in semiconductor technology came from private sector development. However, the U.S. federal government played a crucial role in the semiconductor industry's development. In the transistor's early days, high costs and lack of market demand made military procurement essential for the semiconductor industry' s survival and further development during the 1950s. The federal government awarded procurement contracts primarily to newly established specialized semiconductor manufacturers. Through government procurement and corporate innovation investment, the United States achieved world leadership in the semiconductor industry.

(3) The Internet. The internet' s development is legendary. To address command-and-control problems under hypothetical nuclear attack scenarios, the Department of Defense funded projects related to the internet, including packet switching, ARPANET (1969), and various protocols including TCP/IP. The National Science Foundation (NSF) also invested heavily in related university research. In the 1980s, NSF began building networks connecting university computer science departments (CSNET) and established dial-up capabilities for exchanging electronic mail—capabilities ARPANET lacked. In 1986, NSF launched the Supercomputer Centers program, connecting five major supercomputer centers nationwide to establish NSFnet, which became the internet backbone and eventually replaced ARPANET. In 1991, the internet established by NSF was opened to the public.

American scholars Steil, Victor, and Nelson wrote regarding U.S. government financial support for new industries: "The role of the U.S. government in creating the internet is like a legend, but like all legends, we must carefully draw the correct lessons. The U.S. government never attempted to build such an internet—in fact, the internet emerged as the evolving result of numerous different projects funded by different government agencies with different, often conflicting, purposes" [**?**].

The Innovation System Driving the IT Revolution

The U.S. National Research Council' s Computer Science and Telecommunications Board (CSTB) conducted multiple studies on information technology development and related policies beginning in the 1990s. Research shows that America' s tremendous post-WWII development in information technology resulted partly from federally funded university research, federally and privately funded industrial research, companies founded by talent flowing between universities and industry, and fruitful interactions among these three components.

CSTB reports note that while IT commercialization success suggests industry is a self-sustaining system, ample evidence demonstrates that federally funded basic research laid the foundation for the entire American information industry. Many industrial advances were built upon government-funded university research, sometimes requiring considerable incubation periods. Many fundamental and basic studies conducted by universities and industry produced entirely new product categories 10–15 years later, becoming billion-dollar industries. Examples include time-sharing, client/server computing, graphical computing, the internet, local area networks, workstations, graphical user interfaces, RISC processors, relational databases, parallel databases, data mining, parallel computing, RAID/disk servers, portable communications, and speech recognition.

CSTB research also identifies two important factors enabling effective government funding: (1) Computing technology research benefits from support by multiple government agencies, including DOD—most notably DARPA—as well as NSF, NASA, DOE, NIH, and other research funding agencies. This diversity brings many benefits, providing researchers with multiple potential support channels and helping ensure broad exploration of different research topics, consideration of wider applications, and coordinated technological development. (2) Strong professional program managers and flexible management structures enhance the effectiveness of computing technology research [**?**].

The Innovation System Promoting High Technology Development

For an extended postwar period, the innovation system that emerged in the United States promoted sustained high technology development through two mechanisms.

(1) Coordination of public and private investment. On one hand, national economic and technological prospects led private enterprises to optimistically estimate that R&D investment would yield profits, resulting in substantial private sector investment in high-tech R&D and correspondingly large increases in R&D funding. On the other hand, the Department of Defense, NASA, DOE, and other agencies continued investing in strategically and defensively important areas, promoting progress in critical fields. Public and private investment patterns differ across sectors: in pharmaceuticals and chemicals, private enterprise funding accounts for half of all support; in electronics and communications, funding comes primarily from well-funded private companies and large-scale defense support. Public and private investment create positive interactions: government funds research that cannot be immediately commercialized, while private enterprises carefully weigh risks and rewards to conduct commercialization research; government policies such as procurement ensure enterprise development and provide conditions for sustained innovation.

(2) Personnel training and free mobility. Government funding of university research trains new generations of young scientific and technical personnel who enter enterprises or start their own ventures. Simultaneously, university researchers are hired by enterprises or establish companies themselves. This development process features rich flows of ideas and personnel among university research, industrial research, and product development, continuously driving technology forward.

Continuous Reform in Response to Challenges

America' s post-WWII emergence as the world' s leading power benefited from historical opportunity: while European nations were devastated by war, the United States gained developmental advantages from wartime conditions. For 25 years after WWII, America held absolute world leadership in economic development and science and technology. However, beginning in the 1970s, with European economic recovery, Japan' s rapid development, and changing international conditions, the United States faced continuous external competition and challenges: the 1970s oil crisis, Japan' s economic challenge in the 1980s, the 2001 "9/11" terrorist attacks, and the current rise of Asian nations such as China and India. These developments have caused relative declines in America' s overall scientific and technological strength and leadership position. Throughout this process, the United States has actively responded to changes, continuously innovating to maintain its world S&T leadership.

From one perspective, American science and technology achieved great development because of innovative measures adopted in response to actual or perceived challenges and threats: during WWII, establishing the OSRD and vigorously developing science and technology aimed to defeat Nazi Germany and Japanese militarism; in the 1950s, responding to Sputnik with a series of effective measures greatly promoted American science and technology development for a considerable period.

The 1980s technology-economic competition between Japan and the United States represented a genuine technological contest. Through government strategic planning and corporate alliances, Japan' s technological innovation capacity increased dramatically, making it a American competitor. Initially manifesting in steel and automobiles, the challenge quickly expanded to high-tech products Americans considered proprietary—semiconductors, computers, and other electronic devices. In the semiconductor market battle with Japan, American enterprises suffered comprehensive defeat. Japanese companies' share of the world integrated circuit market increased from 24% in 1980 to 50% in 1988, while the U.S. share declined from 67% to 38% during the same period [**?**]. During the 1980s, Japan also began leading in technologies where America had previously dominated, such as televisions, cameras, tape recorders, machine tools, and robotics.

Under impact from Japan' s technological-economic challenge, the U.S. government changed its previous hands-off approach to private enterprises and began expanding the use of federal funds to support collaboration among government research institutions, universities, and enterprises. From the 1980s to early 1990s, Congress enacted a series of laws encouraging cooperation among federal agencies, universities, and private enterprises and promoting technology transfer. Programs were launched to fund and incentivize industrial R&D and related university and federal laboratory activities, such as the Small Business Innovation Research program, Engineering Research Centers program, Advanced Technology Program (ATP), and tax incentives to attract industrial investment in university basic research, equipment, and personnel training. Simultaneously, with government support, American enterprises began forming R&D consortia: in 1987, 14 semiconductor companies formed SEMATECH to research next-generation chip manufacturing systems, with the core goal of surpassing Japan in photolithography technology. In 1988, the Department of Defense decided to provide SEMATECH with matching funds of $100 million annually through ARPA. This investment paid off: SEMATECH contributed significantly to America regaining world leadership in semiconductor markets.

In 1992, as the economy fully recovered, American manufacturers recaptured world semiconductor market leadership from the Japanese. Symbolically, that year Japan declared its decade-long "Fifth Generation Computer Project" a failure, while the United States, with the internet opening to society, ushered in a new era of information technology, driving economic prosperity from 1995–2000.

Entering the 21st century, with the rise of China, India, and other Asian countries and the strengthening of their scientific and technological capabilities, the United States faces comprehensive S&T competition in a globalized context. American scientific communities and think tanks have conducted extensive research to advise government decision-making. Most influential was the National Academy of Sciences' 2005 advisory report *Rising Above the Gathering Storm*, which proposed recommendations for revitalizing American science, including creating an agency within the Department of Energy similar to DARPA, which could be called the Advanced Research Projects Agency-Energy (ARPA-E). In 2007, ARPA-E was officially created under the America COMPETES Act.

Today, against a backdrop of globalized development, American science and technology development is inseparable from developments in other countries, and U.S. efforts to maintain its leadership will inevitably influence science and technology development in other nations.

Conclusion

The United States' emergence as a world science and technology power resulted from a historical developmental process built upon internal endowments and favorable external environments. Natural connections to European culture allowed American science to fully absorb nourishment from European scientific traditions, follow world scientific frontiers, and ultimately catch up with and surpass European science. In industrial and economic development, leveraging abundant resources and a vast market, America seized opportunities from industrial revolutions to surpass Britain and Germany in technology within a relatively short time, with rapid economic and productivity growth. Unlike European nations, American economic, social, educational, and scientific development occurred with minimal federal government intervention, which, combined with America' s tradition of free migration, created a system of free competition in both economy and science. Enterprise innovation capacity emerged internally in response to market competition signals, while scientific research similarly emphasized academic freedom and competition, stressing bottom-up creativity. Under these developmental conditions, to meet WWII challenges, the U.S. government and scientific community established a new relationship, building an innovation system characterized by partnership among government, academia, and industry. This massive system featured strong policies and measures that were continuously renewed and developed in practice, helping to "win World War II, put a man on the moon, decode the human genome, and nurture economic growth" [**?**].

In summary, four aspects constitute important factors in America becoming a world science and technology power:

(1) **Adherence to the spirit of free inquiry and scientific autonomy.** The purpose of science is to discover truth; free inquiry is the soul of science, and autonomy means scientists' independent judgment of their work and freedom from control by other social factors. This spirit and principle represents consensus within the scientific community and has gained recognition from government and industry. Articulated in Vannevar Bush' s *Science–The Endless Frontier* report, it has become a nearly abstract principle profoundly influencing American science policy [**?**]. Even under later developments emphasizing national objectives and macro-coordination mechanisms, this spirit and principle continue to govern the American scientific community.

(2) **Interaction between basic research and applications.** The United States emphasizes basic research, which not only produces original achievements but also contributes enormously to industry and economic development. Basic research can contribute to industry and economy because in America it is conducted within a broad application context: (a) practice-oriented American universities; (b) mission-oriented research predominantly funded by government; (c) enterprises with strong innovation capabilities that conduct both long-term basic research and absorb and digest the latest scientific knowledge; and (d) extensive exchange and cooperation in personnel and projects between universities and enterprises. Through these mechanisms, basic research and applications can interact closely and effectively, with basic research results applied in practice by enterprises or other entities, generating excellent public benefits and returns on public investment in basic research.

(3) **Pluralistic investment mechanisms.** America' s unique pluralistic investment mechanism creates a hybrid system of public (government)

funding and private funding (enterprises, private foundations, universities, venture capital, etc.) that collaboratively supports activities across the entire innovation chain. At the government level, multiple departments and agencies support S&T development, which helps stimulate original innovation and open new strategic research directions.

(4) **Cultural environment that incentivizes innovation.** American culture encourages individual creativity, risk-taking, and tolerance for failure—factors that incentivize innovation in science and technology. Both DARPA, which supports disruptive innovation, and Silicon Valley, which nurtures innovative enterprises, exemplify the significance of an innovation culture for breakthrough S&T development.

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Note: Figure translations are in progress. See original paper for figures.