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Breaking New Ground or Breaking the Rules

Glenn R. Fong

Strategic Reorientation in
U.S. Industrial Policy

Whether it has been in the process of building a new nation or the new economy, the United States has had to grapple with enduring industrial policy issues. At the time of the Founding Fathers, the question was how the then-less developed new nation should meet the challenge of Britain's manufacturing prowess, and whether it should adopt Alexander Hamilton's infant industry proposals for industrial subsidies and trade protection. Jumping ahead more than two centuries, the issues have included whether to dismantle the Department of Commerce and eliminate corporate welfare. Most recently the debate has reached into cyberspace, including whether to exempt internet commerce from taxes and legislate protections for online privacy.

The common thread across these different eras and issues is the role played by industrial policies—broadly defined as government measures that affect business operations, whether positive or negative, intended or unintended. The powerful association of the U.S. economy with the laissez-faire paradigm leads many to question whether industrial policies exist at all in the United States. For instance, former White House Chief of Staff John Sununu was quoted as saying, "We don't do industrial policy."¹ Empirical evidence demonstrates otherwise. To cite one striking indicator, the Congressional Budget Office estimates that federal support for business in the form of financial subsidies, credit programs, loan guarantees, and tax preferences amounts to more

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1. Quoted in Otis L. Graham, Jr., *Losing Time: The Industrial Policy Debate* (Cambridge, Mass.: Harvard University Press, 1992), pp. 231–232.

than \$100 billion annually.² For better or worse, the United States does do industrial policy.

This article examines nine case studies in U.S. industrial policy: (1) Sketchpad, 1961–63, pioneered interactive computer graphics; (2) ARPANET, 1967–75, created the first internet; (3) the Very High Speed Integrated Circuit Program (VHSIC), 1980–88, advanced digital signal processing technology; (4) the Strategic Computing Program (SCP), 1983–92, promoted massively parallel computing and artificial intelligence; (5) Sematech, 1987–present, carries out semiconductor manufacturing research and development (R&D); (6) the Advanced Lithography Program (ALP), 1988–present, pushes the technology for shrinking more transistors on a chip; (7) the Advanced Technology Program (ATP), 1990–present, promotes the commercialization of new technologies; (8) the High Performance Computing and Communications Initiative (HPCC), 1992–present, funds supercomputer research and high-speed fiber optic networks; and (9) the National Flat Panel Display Initiative (NFPDI), 1994–98, supported flat panel electronic display technologies.

These cases are formally technology programs that may not ordinarily be examined from an industrial policy perspective.³ Yet technology projects can fundamentally bolster industrial competitiveness by contributing to the commercial technology base and the manufacturing, industrial base of an economy. Technology programs as instrumentalities of industrial policy, more than an analytical construct, are widely implemented in public policy. Foreign government-sponsored technology programs such as Japan's Very Large Scale Integration Project of the 1970s and its Fifth Generation Computer Project of the 1980s have long been centerpieces of government strategies for national economic restructuring.⁴ GATT (General Agreement on Tariffs and Trade) Uruguay Round attention to the potential market biases introduced by government R&D subsidies further substantiates the industrial policy as well as trade policy relevance of technology initiatives.⁵

2. U.S. Congress, Congressional Budget Office, *Federal Financial Support of Business*, July 1995.

3. The association made here between technology policy and industrial policy has not, in this particular work, been prompted by the agencies or firms under study. Furthermore, the author recognizes that the parties involved may wish to avoid the association with industrial policy, if only to minimize politically adverse reactions. The author apologizes for any such reactions that may arise from this article.

4. See Glenn R. Fong, "State Strength, Industrial Structure, and Industrial Policy: American and Japanese Experiences in Microelectronics," *Comparative Politics*, Vol. 22, No. 3 (April 1990), pp. 273–299; and Fong, "Follower at the Frontier: International Competition and Japanese Industrial Policy," *International Studies Quarterly*, Vol. 42, No. 2 (June 1998), pp. 339–366.

5. For analyses of the links between technology policy, economic growth, and international competitiveness, see Michael Borrus and Jay Stowsky, "Technology Policy and Economic Growth," in

The commercial relevance of any specific technology program varies from case to case. Indeed, in the debate over U.S. industrial policy, many doubt the federal government's capacity to carry out industrial policies in explicit support of economic competitiveness. As observed by the Congressional Research Service (CRS), U.S. industrial policies are "ad hoc, uncoordinated, and based primarily upon the government's concern with defense."⁶ In one of the most trenchant critiques, Ira Magaziner and Robert Reich have stated that the United States has an industrial policy by default, a plethora of individual programs across which the "goal of international competitiveness has not figured."⁷

These reservations might appear to apply to the cases selected for this discussion given their association with national defense rather than industrial policy objectives. Sketchpad, ARPANET, SCP, ALP, and Sematech have been managed by the Defense Advanced Research Projects Agency (DARPA or ARPA),⁸ the Pentagon's central R&D organization. VHSIC and NFPDI were managed out of the higher-level office of the undersecretary of defense responsible for technology strategy at the Department of Defense (DoD).⁹ HPCC is a multiagency initiative that includes DARPA along with eleven other federal agencies. Only ATP operates completely outside of the military R&D appara-

Lewis M. Branscomb and James H. Keller, eds., *Investing in Innovation: Creating a Research and Innovation Policy That Works* (Cambridge, Mass.: MIT Press, 1998), pp. 40–63; Harold Brown and Charles Herzfeld, *Global Innovation/National Competitiveness* (Washington, D.C.: Center for Strategic and International Studies, 1996); Council on Competitiveness (CoC), *Endless Frontier, Limited Resources: U.S. R&D Policy for Competitiveness* (Washington, D.C.: CoC, April 1996); Council on Competitiveness, *Gaining New Ground: Technology Priorities for America's Future* (Washington, D.C.: CoC, March 1991); Jeffrey A. Hart, "The Use of R&D Consortia as Market Barriers: Case Studies of Consortia in the United States, Japan, and Western Europe," *International Executive*, Vol. 35, No. 1 (January/February 1993), pp. 11–33; Martha Caldwell Harris and Gordon E. Moore, eds., *Linking Trade and Technology Policies: An International Comparison of the Policies of Industrialized Nations* (Washington, D.C.: National Academy Press, 1992); David C. Mowery and Nathan Rosenberg, "New Developments in U.S. Technology Policy: Implications for Competitiveness and International Trade Policy," *California Management Review*, Vol. 27, No. 1 (Fall 1989), pp. 107–124; and Laura D'Andrea Tyson, *Who's Bashing Whom? Trade Conflict in High Technology Industries* (Washington, D.C.: Institute for International Economics, 1993).

6. U.S. Library of Congress, Congressional Research Service, "The Debate over a National Industrial Policy toward Technology and Economic Growth," 92-426 SPR, May 11, 1992, p. 1.

7. Ira C. Magaziner and Robert B. Reich, *Minding America's Business* (New York: Harcourt, 1982), p. 255; see also pp. 200, 235–246, 258–259, 326.

8. The agency was founded in 1958 as ARPA (no "Defense"), changed to DARPA in 1972, reverted back to ARPA in 1993, and then back to DARPA in 1995. The acronym used in this article will shift according to the time period under discussion.

9. At the time of VHSIC, this office was the Office of the Undersecretary of Defense for Research and Engineering. At the time of NFPDI, this office was the Office of the Undersecretary for Acquisitions and Technology. Its present designation is the Office of the Undersecretary for Acquisitions, Technology, and Logistics.

tus, being managed by the Department of Commerce's National Institute of Standards and Technology.

Yet these cases do shed important light on U.S. industrial policymaking capabilities. Contrary to the doubts of the policy and academic communities, the cases demonstrate the increasing capability of the federal government not only to craft technology and industrial policy measures, but to do so in explicit support of U.S. economic competitiveness. Depending on the side taken in the industrial policy debate, this enhanced capability may be viewed either as a progressive "breaking of new ground" or problematic "breaking of the rules." Either way, the findings bring into question the extent to which limitations apply to industrial policy in the United States.

The next section of this article establishes the rationale for the selection of the nine cases, highlighting their contributions in the field of information technology. This section also develops a fivefold typology to help conceptualize the reorientation in U.S. industrial policy toward the explicit support of the economic competitiveness of U.S. industry. This analytical framework also helps to specify the varied relationships that exist between defense technology programs and civilian, commercial technology development. Dual-use technology and policy issues have been of long-standing interest in security studies,¹⁰ and the framework offers an improved understanding of that military-civilian interface.

The case studies are then analyzed using the fivefold typology. ARPANET and Sketchpad are examples of a by-product model in which commercial spillovers from military programs are entirely incidental and happenstance. VHSIC and SCP are cases of intentional spin-off in which civilian benefits are programmatically anticipated. ALP and HPCC are explicit dual-use cases in which commercial and military objectives are of relatively equal importance. Sematech and NFPDI fit an industrial base model in which commercial benefits can exceed military ones. And ATP is representative of an economic competitiveness model wherein any noncommercial objectives fall away entirely.

Significantly, this distribution across the typology roughly corresponds to the chronological sequencing of the cases, and evidences an important evolution and reorientation in U.S. industrial policy. These trends are further substantiated in the concluding section that briefly surveys more than a half dozen

10. An excellent example is John A. Alic, Lewis M. Branscomb, Harvey Brooks, Ashton B. Carter, and Gerald L. Epstein, *Beyond Spinoff: Military and Commercial Technologies in a Changing World* (Boston: Harvard Business School Press, 1992).

other technology programs, including the recently announced National Nanotechnology Initiative.

Industrial Policy Models

Information technology (IT) is now the largest industry in the United States, generating more than 8 percent of the country's output and employing 7.4 million people at wages 64 percent higher than average. Growing 57 percent in revenues and accounting for 45 percent of U.S. industrial growth in the 1990s, IT is the central driving force behind the much-touted "new economy" or "digital economy."¹¹ The nine case studies discussed here represent the leading edge of federal investments in IT over the past four decades. HPCC constitutes the country's farthest-reaching R&D in computer science and networking. VHSIC and Sematech have been the government's most concerted efforts in semiconductor technology. The same could be said for NFPDI with respect to next-generation electronic display technology. And ATP is second only to traditional standards and measurements laboratory work when it comes to the Commerce Department's research and development in IT. Of the four remaining cases, all have been highlighted in major surveys of key military programs in information technology.¹²

Whereas most federal R&D in information technology is devoted to nearer-term development and testing of IT applications for possible government procurement—most notably for defense systems—the cases discussed here are among the most ambitious and/or longer-term endeavors to extend the frontiers of IT. The nine programs represent the government's best effort at first pioneering and then maintaining and extending U.S. leadership in information technology.

Consensus in the policy and academic communities would not hold much confidence in the U.S. government's ability to effectively shape the country's IT future. National and cross-national studies have highlighted a series of structural attributes particularly determinative of a country's industrial

11. "Information Technology Field Is Rated Largest U.S. Industry," *New York Times*, November 18, 1997; U.S. Department of Commerce, *The Emerging Digital Economy*, April 1998; and "Infotech Packs a Hefty Wallop," *Business Week*, April 27, 1998, p. 50.

12. Arthur L. Norberg and Judy E. O'Neill, *Transforming Computer Technology: Information Processing for the Pentagon, 1962–1986* (Baltimore, Md.: Johns Hopkins University Press, 1996); and Sidney G. Reed, Richard H. Van Atta, and Seymour J. Deitchman, *DARPA Technical Accomplishments*, 3 vols. (Alexandria, Va.: Institute for Defense Analysis, February 1990, April 1991, and July 1991).

policymaking capability—and point to U.S. deficiencies in each area.¹³ One area relates to the array of industrial policy instruments that a government may have at its disposal—an array limited in the United States to a combination of untargeted macroeconomic policies and more specific but detrimental protectionist trade measures. A second area relates to state structure and the coordination problems that arise in the United States from the decentralization of industrial policymaking authority across scores of federal agencies, congressional committees, and individual state and local governments. A third area relates to policy networks that build public and private sector consensus in the design and implementation of industrial policies, and the paucity of such networks in the United States. A fourth area concerns state autonomy, and the relative inability of U.S. government officials to focus on long-term industrial strategies in the face of short-term-oriented political pressures and private interests.

The fifth area concerns the policy objectives that underlie the conduct of industrial policy. Even the most coherent, autonomous state with a vast array of targeted policy instruments supported by well-institutionalized policy networks will contribute little to national economic competitiveness if it deploys its resources for ends unassociated with or contrary to competitiveness. This article focuses on this fifth dimension: the degree to which industrial policies are employed as part of a coherent strategy to enhance economic competitiveness. The nine case studies are analyzed with respect to their underlying policy objectives.

This analysis focuses on the specific missions and objectives of each program, especially during their formulation, rather than on their economic impact or technological achievements. Certain technical and economic results of the initiatives are referenced, but this is done more to reveal their relationship to issues of economic competitiveness than to offer comprehensive assessments of programmatic effectiveness or accomplishments. At issue is not

13. For cross-national studies, see Peter B. Evans, Dietrich Rueschemeyer, and Theda Skocpol, eds., *Bringing the State Back In* (Cambridge: Cambridge University Press, 1985); Jeffrey A. Hart, *Rival Capitalists: International Competitiveness in the United States, Japan, and Western Europe* (Ithaca, N.Y.: Cornell University Press, 1992); Peter J. Katzenstein, ed., *Between Power and Plenty: Foreign Economic Policies of Advanced Industrial States* (Madison: University of Wisconsin Press, 1978); and John Zysman, *Governments, Markets, and Growth: Financial Systems and the Politics of Industrial Change* (Ithaca, N.Y.: Cornell University Press, 1983). For U.S. studies, see Stephen D. Krasner, *Defending the National Interest: Raw Materials Investments and U.S. Foreign Policy* (Princeton, N.J.: Princeton University Press, 1978); Magaziner and Reich, *Minding America's Business*; and John Zysman and Laura Tyson, eds., *American Industry in International Competition: Government Policies and Corporate Strategies* (Ithaca, N.Y.: Cornell University Press, 1983).

whether any of these programs have succeeded in any technical or economic sense, but whether they were conceptualized to have broad economic benefit in the first place.

General analyses of the objectives manifest in U.S. industrial policy highlight deficiencies as great as, if not greater than, the other structural arenas. Rarely, if ever, are government policy measures engaged for the explicit purpose of enhancing national economic competitiveness. Instead industrial policy measures are most often employed in service of a variety of economic, political, foreign policy, or social objectives that have an indirect relationship, if any, to industrial competitiveness. Examples of such noncompetitiveness objectives include job creation, domestic coalition building, global alliance building, and social welfare. Without judging their broader legitimacy, the literature shows that such objectives have often proven to be detrimental to industrial competitiveness.¹⁴

A classic example of this larger argument is how a set of powerful noncompetitiveness objectives came to dominate federal technology policymaking after World War II.¹⁵ In this postwar paradigm, the private sector is the driving force behind U.S. technological progress, and the government plays the secondary role of providing a favorable macro environment for innovation. Echoing broader assessments of U.S. industrial policy, the private-sector Council on Competitiveness points out that the United States is unique among leading industrial countries because "it has not singled out industrial competitiveness as one of its national R&D priorities."¹⁶

Direct government support for R&D has traditionally been limited to only two relatively narrow areas: basic research and mission agency R&D. Federal funding for basic research is necessary to make up for private sector underinvestment in fundamental science. This market failure stems from the highly

14. See Zysman and Tyson, *American Industry in International Competition*.

15. The classic statement of this postwar paradigm is *Science: The Endless Frontier*, report to the president by Vannevar Bush, director of the Office of Scientific Research and Development, July 1945. Analysis can be found in National Academy of Engineering, *Mastering a New Role: Shaping Technology Policy for National Economic Performance* (Washington, D.C.: National Academy Press, 1993), chap. 1; Lewis M. Branscomb, "New Policies in Old Bottles: Adapting Federal Agencies to the New Economic Agenda," *Business and the Contemporary World*, Vol. 7, No. 2 (1995), pp. 28–43; Harvey Brooks, "The Evolution of U.S. Science Policy," in Bruce L.R. Smith and Claude E. Barfield, eds., *Technology, R&D, and the Economy* (Washington, D.C.: Brookings, 1996), pp. 15–48; David Mowery, "The Practice of Technology Policy," in Paul Stoneman, ed., *Handbook of the Economics of Innovation and Technical Change* (Oxford: Blackwell, 1995), pp. 513–557; National Academy of Sciences, *Allocating Federal Funds for Science and Technology* (Washington, D.C.: National Academy Press, 1995); and Bruce L.R. Smith, *American Science Policy since World War II* (Washington, D.C.: Brookings, 1990).

16. Council on Competitiveness, *Gaining New Ground*, p. 13.

problematic prospects of appropriating benefits from private investments in high-risk, uncertain, and long-term basic research endeavors. Government R&D in support of the core missions of individual government agencies—for instance, public health and the National Institutes of Health, space exploration and NASA, and national security and DoD—is also necessary. Here too the private sector will underinvest because of the limited and uncertain markets in such areas as exploratory medicines, launch vehicles, and advanced weaponry.

This postwar paradigm sets a benchmark for gauging the relationship between government R&D and economic competitiveness. In the orthodox paradigm, government R&D is designed to overcome specific market failures rather than to enhance national economic competitiveness. The link between basic research and mission agency R&D on the one hand and economic competitiveness on the other, although potentially substantial, is nevertheless happenstance and indirect. Again reflecting assessments of U.S. industrial policy generally, Mary Good, former undersecretary of commerce for technology in the Clinton administration, has observed, “The U.S. government has had a technology policy by default since World War II based on trickle down ‘spin-offs’ from military research and blind luck in health research.”¹⁷ At worst, the link may be counterproductive where, most notably, military R&D might divert finite resources away from commercial technology endeavors.

Certain military-supported technologies no doubt have made contributions to commercial competitiveness. At variance, however, is the degree to which this military-civilian interface has been explicitly programmed as a matter of policy design—an issue that strikes at the core of the notion of policy objectives.

To analyze the varied policy objectives underlying the nine case studies, this article utilizes the following typology:

1. By-product Model: If military R&D has entailed spillovers into the commercial sector, it has traditionally done so in an unanticipated, incidental fashion. In this by-product model, the conduct of defense research is exclusively guided by mission agency military requirements. Commercial spin-offs are not avoided and may become quite significant. But any such by-products are unintended from a policy planning perspective, and are considered beyond the consideration of DoD.

17. Quoted in Henry Etzkowitz, “Clinton Administration Unites Science, Technology, and Industrial Policies,” *Technology Access Report*, Vol. 6, No. 12 (December 1993), p. 1.

2. **Intentional Spin-off Model:** In this approach, commercial spillovers are expressly contemplated during program planning and implementation. Such spillovers may even be regarded by defense officials as programmatic benefits, though of a secondary nature. But in this intentional spin-off model, defense research remains overwhelmingly guided by military needs. And the actual “harvesting” of the anticipated commercial benefits is considered beyond the Pentagon’s jurisdiction, and is left to the efforts of the private sector.
3. **Explicit Dual-Use Model:** In this model, defense technology projects have the express purpose of benefiting commercial as well as military needs. Projects focus on a level of technical work that is generic to both the military and civilian sectors. Although technologies developed in the first two models may indeed have dual-use utility, this third approach pursues such technologies explicitly and programmatically. This explicit intent, as well as a balancing between military and commercial objectives, defines this category more narrowly for this analysis than more general uses of the “dual-use” term.
4. **Industrial Base Model:** In this approach, the commercial orientation of defense programs, at least operationally, exceeds the defense orientation. One purpose of industrial base programs remains military benefits, namely, access to leading-edge technologies and capabilities. But in this model, such benefits are gained only after commercial technology and civilian industrial advances are supported by DoD. The commercial and civilian focuses of such programs are justified on the grounds that it is necessary to establish or bolster the civilian technology and industrial base so that spin-ons can accrue to the defense technology base.
5. **Economic Competitiveness Model:** In this approach, any vestige of national security or other mission agency rationale is jettisoned, and unabashed support is given to commercial technology. Such purely civilian-oriented technology policy is usually associated with R&D programs of U.S. economic rivals in Asia and Europe.

Figure 1 shows the nine cases arrayed across the typology. Using illustrative ratios to help differentiate the categories, models 1 and 5 are near pure cases—100 percent military oriented or 100 percent civilian oriented—while model 3 stands at 50/50. Model 2 could be 75/25 defense biased, whereas model 4 is closer to 25/75. Model 1 would be recognized by the policy and academic communities as the most orthodox position for U.S. industrial policy—reflecting traditional mission agency objectives and the limited role of the federal gov-

Figure 1. Industrial Policy Objectives.

	By-product Model	Intentional Spin-off Model	Explicit Dual-Use Model	Industrial Base Model	Economic Competitiveness Model
Sketchpad (1981)	██████████				
ARPANET (1967)	██████████				
VHSIC (1988)		██████████			
Strategic Computing (1988)		██████████			
Sematech (1987)			██████████		
Advanced Lithography (1988)			██████████		
ATP (1988)					██████████
HPCC (1992)			██████████		
Flat Panel Displays (1994)			██████████		
Military/Commercial Objectives Ratio (Illustrative)	100:0	75:25	50:50	25:75	0:100

ernment generally. Any movement off this first position may be viewed as either “breaking new ground” or “breaking the rules.”

This typology also makes an important contribution to considerations of dual-use technology and policy. In the policy realm as well as in the academic literature, the term “dual-use” may be used in ways consistent with any of the first four models presented here—from instances of accidental dual-use benefits to explicit defense investments in civilian industries. This broad range in usage can create conceptual misunderstandings and policy confusion, so much so that the CRS has issued a fact sheet for members of Congress to distinguish between “DoD programs that develop dual-use technologies and DoD’s ‘dual-use’ technology development programs.”¹⁸ Even this CRS characterization is ambiguous and blurs the multiple ways in which dual-use technologies may be developed. The finer distinctions made by this article are, to use CRS’s words, “more than semantic,” as the different policy objectives across the typology shape how specific programs should be considered and assessed. To avoid contributing to further confusion, this analysis will use the

18. Congressional Research Service, “The Difference between DoD Programs That Develop Dual-Use Technologies and DoD’s Dual-Use Technology Development Programs: A Fact Sheet,” 95-738 SPR, January 17, 1997, p. 1.

dual-use term only with respect to model 3 attributes of the explicit pursuit and balancing of military and commercial objectives.

Similar complexities apply to the “spin-on” concept in which technology originating in the civilian sector is diffused to the defense realm rather than the reverse spin-off direction. Here too it is important to make distinctions between programmed and unprogrammed technology transfer from commercial to defense technology. Hence model 4 is crafted more narrowly than general conceptions of spin-on by emphasizing the purposeful intent to engineer the spin-ons rather than leaving the diffusion to chance. Even though the typology offered here is anticipated in the wider community, the exact labeling is original to this analysis.¹⁹

By-product Model

DARPA’s research program historically has typified the classic relationship between mission agency R&D and economic competitiveness. Since its inception in 1958, DARPA has supported the development of military-specific weapons technology as well as more generic technologies with the potential for military application. The former have included ballistic missile defense and tactical antitank weapons technologies, and even the M-16 rifle. The latter have included R&D in new materials, novel energy sources, and biomedical technologies. Historically, in both categories—and akin to much of NASA’s space program—commercial spin-offs were mere afterthoughts. Afterthoughts notwithstanding, spin-offs have occurred in a big way. In the vein of the NASA cases of Tang, Teflon, and Velcro, a primary source for DARPA spin-offs has been its computer science work. Two such efforts—ARPANET and Sketchpad—illustrate DoD’s by-product interface with civilian technology particularly well.

ARPANET

The ARPA-internet story is among the most renowned of by-product cases.²⁰ ARPA’s intercomputer communications research began in 1967. The initial objective was to network the agency’s thirty-odd university contractors involved

19. For a related eight-category typology, see Alic et al., *Beyond Spinoff*, pp. 64–75.

20. Reed, Van Atta, and Deitchman, *DARPA Technical Accomplishments*, Vol. 1, chap. 20; Norberg and O’Neill, *Transforming Computer Technology*, chap. 4; Vinton Cerf, “How the Internet Came to Be,” in Bernard Aboba, ed., *The Online User’s Encyclopedia* (Reading, Mass.: Addison-Wesley, 1993); Barry M. Leiner et al., “A Brief History of the Internet” (1997), <http://www.isoc.org/Internet-history/>; and Jeffrey A. Hart, Robert R. Reed, and François Bar, “The Building of the Internet: Implications for the Future of Broadband Networks,” *Telecommunications Policy*, Vol. 16, No. 8 (November 1992), pp. 666–689.

in computer research, and allow them to share computing capabilities, programs, and files. Ultimately, the entire defense community—the Pentagon, the services, and their contractors—was envisioned to be the network’s major user.

The first wide-area ARPANET (for ARPA network) was set up between four sites in 1969. By 1973 the network was extended to more than forty nodes, and had become available to the larger defense community. In 1975 ARPANET, with nearly 100 nodes, was transferred to the Defense Communications Agency (now the Defense Information Systems Agency) as an operational network. Up to this point, ARPA had invested \$25 million in the project.

ARPANET’s commercial spin-offs cannot be overemphasized. The program pioneered a distributed, decentralized computer network rather than a centrally controlled system. It inaugurated the notion of segmenting data into “packets” to expedite network transfers. ARPA’s research served as the basis for most of the early commercial data networks including: (1) TELENET, the first commercial packet switching communications service; (2) Ethernet, the earliest local area network (LAN) developed by Xerox; (3) BITNET, the IBM-based electronic mail network; and (4) Usenet, the ATT/UNIX-based “poor man’s ARPANET.” The ARPA program also established the all-important network-to-network protocols for connecting the multiplying independent networks. Such protocols created the “inter” for the “net.”

Yet ARPA cannot be credited with masterminding the present-day internet. ARPANET was entirely mission agency-oriented with no civilian pretensions. It is commonly reported that ARPANET was created to serve as a distributed, redundant communications network that could survive a nuclear first strike, but its architects have soundly discounted such a narrowly focused military motivation.²¹ Even so, their focus remained purely mission oriented: enhancing communications among ARPA’s university and industry contractors. Before the network was established, in a spokes-without-the-wheel structure, ARPA had to maintain simultaneous and separate time-sharing telephone links to each of its contractors. Frustration with such an inefficient and costly communications infrastructure inspired the ARPANET.²² Still it was an ARPANET for ARPA and ARPA contractors. Unintentionally contributing to commercial computer networking, and purposefully doing so, are two different matters.²³

21. Leiner et al., “A Brief History of the Internet.”

22. Discovery Channel Online, “History of the Internet,” <http://www.discovery.com/DCO/doc/1012/world/technology/Internet/inet1.4.html>.

23. The direct architects of today’s internet are to be found in the National Science Foundation rather than in ARPA. See Hart, Reed, and Bar, “The Building of the Internet.”

An astounding example of an unintended ARPANET spillover is one of the most prominent features of today's internet: electronic mail. ARPANET's primary concern was for information resource sharing—transferring files and downloading software programs. The concept of electronic text communication—e-mail—was unanticipated and overlooked five years into the project. Only as an afterthought was e-mail experimented with over the network in 1971. In what would become one of the most popular applications on the ARPANET, e-mail's overnight success took the agency completely by surprise.²⁴ As significant as this afterthought may have been, by-product it remains.

SKETCHPAD

Interactive computer graphics has been a second major area of ARPA investment to produce substantial commercial spillover.²⁵ The fundamental concepts behind “the remarkable computer graphic images we encounter every day emerged primarily from research projects funded by IPTO”—the Information Processing Techniques Office of ARPA.²⁶ The first such project, Sketchpad in the early 1960s, pioneered computer rendering and manipulation of two-dimensional geometric shapes.²⁷ Follow-on ARPA research would be the first to solve such issues as the elimination of hidden areas behind front surfaces and clipping-off images that are partially off-screen. Later ARPA-sponsored work on three-dimensional graphics, high-resolution monitors, and graphics-intensive workstations led directly to the founding of the computer maker Silicon Graphics in 1982.

Other commercial spillovers have involved the mobility of key personnel. For instance, an ARPA-funded researcher who pioneered the rendering of curved surfaces and the first computer simulation of a human later became the

24. Ian R. Hardy, “The Evolution of ARPANET Email” (1996), http://server.berkeley.edu/virtual-berkeley/email_history.

25. Reed, Van Atta, and Deitchman, *DARPA Technical Accomplishments*, Vol. 2; Norberg and O'Neill, *Transforming Computer Technology*, chap. 3; Edward R. McCracken, “Computer Graphics: Ideas and People from America's Universities Fuel a Multibillion-Dollar Industry,” in Computing Research Association (CRA), *Computing Research: A National Investment for Leadership in the Twenty-first Century* (Washington, D.C.: CRA, 1997), pp. 11–15.

26. Norberg and O'Neill, *Transforming Computer Technology*, p. 151. IPTO (and its subsequent incarnations including the present-day Information Technology Office) is one of a half dozen technical offices within the agency.

27. The initial Sketchpad project was not directly funded by DARPA, but was developed using DARPA-sponsored computer hardware and software, and was enthusiastically encouraged by the agency. Reed, Van Atta, and Deitchman, *DARPA Technical Accomplishments*, Vol. 2, chap. 13, p. 6.

head of computer graphics at Lucasfilm; produced graphics for the *Star Trek* film series; and then cofounded Pixar, where he has helped make the blockbusters *Toy Story* and *A Bug's Life*. Another ARPA-supported graphics researcher went on to found Adobe Systems, which set the industry standard for rendering text and graphics for laser printers.

Despite these dramatic spillovers, Sketchpad was undertaken for mission agency purposes. Sketchpad sought to enhance the presentation of information to military personnel via graphics rather than just numbers or text: "The processing of pictures is a task of fundamental importance to the DoD. Pictures are, for example, basic ingredients of the intelligence estimates which guide strategic planning. Reconnaissance imagery similarly dictates day-to-day tactical decisions, and real-time image transmission is assuming ever greater importance with increasing use of remotely piloted vehicles. . . . For these reasons, IPTO has organized a substantial program of basic research [in] digital picture processing. . . . This program seeks to develop understanding of digital images and their transformations as a foundation for later practical use by DoD." At the same time, ARPA researchers and program managers "could not know that the pictures and processes they produced experimentally would lead to widespread use of computer graphics in business, industry, science, and the arts."²⁸ As a form of industrial policy, the by-product model is rudimentary and fortuitous.

Intentional Spin-off Model

Beginning in the late 1970s, DoD technology programs sought to purposely do what ARPANET and Sketchpad did only incidentally: make a direct connection between defense research and the commercial marketplace. In establishing this connection, DoD technology programs began a reorientation in policy objectives toward the incorporation of commercial economic considerations. In the 1980s, this reorientation would still leave actual commercial applications from defense work to the private sector. But commercial spin-offs were no longer afterthoughts; instead they would be considered in the very formulation of DoD programs. The first major steps in this intentional spin-off direction were the Very High Speed Integrated Circuit and Strategic Computing Programs.

28. Norberg and O'Neill, *Transforming Computer Technology*, pp. 119, 142.

VERY HIGH SPEED INTEGRATED CIRCUITS

Established in 1980, but in formulation from 1977, VHSIC was the government's largest, most ambitious effort in semiconductor technology since the early 1960s.²⁹ VHSIC had an eight-year, \$1 billion budget and involved twenty-five different companies. Reflecting mission agency objectives, VHSIC's primary aim was to advance semiconductor technologies to meet military requirements—notably, circuits with state-of-the-art minimum features sizes in the micron and submicron range³⁰ and high-speed computational throughput. But to achieve that objective, the program was cast to reintegrate the commercial semiconductor industry into the defense technology base. Although defense-related work was crucial to the very birth of the industry in the 1950s, chip makers subsequently reoriented themselves toward burgeoning commercial markets at the expense of meeting military needs. Without the participation of mainstream semiconductor firms, Pentagon planners doubted the long-term viability of VHSIC technology.

This need to reach out to mainstream chip makers led to the intentional spin-off characteristics of the VHSIC program. Pentagon officials explicitly sought to align the substance of VHSIC's objectives with leading-edge industry efforts. DoD organizers specifically highlighted the prospects of commercial benefits from VHSIC work, including developments in the areas of advanced lithography equipment, fabrication technology, and new architectures. DoD estimated that "over 75 percent of the VHSIC program will provide either direct or indirect fallout to the consumer marketplace."³¹

VHSIC was far from a commercial-oriented industrial policy program. The program's commercial benefits were anticipated but nevertheless secondary side products and indirect spillovers. Military-specified and defense-tailored circuits were the prime targets of the VHSIC program. But for Pentagon planners and commercial semiconductor firms alike, the civilian spin-offs were the hook to bring in the military deliverables. As such, the commercial-military

29. Portions of this section are based on Glenn R. Fong, "The Potential for Industrial Policy: Lessons from the Very High Speed Integrated Circuit Program," *Journal of Policy Analysis and Management*, Vol. 5, No. 2 (Winter 1986), pp. 264–291; Fong, *Federal Support for Industrial Technology: Lessons from the VHSIC and VLSI Programs* (U.S. Congress, Office of Technology Assessment, December 1987); and Fong, "The Future of Pentagon-Industry Collaboration in Technology Development," in Andrew L. Ross, ed., *The Political Economy of Defense: Issues and Implications* (New York: Greenwood, 1991), pp. 67–90.

30. One micron is one-thousandth of a millimeter. A human hair is about 100 microns in diameter, and cigarette paper is about 25 microns thick.

31. Ruth M. Davis, "The DoD Initiative in Integrated Circuits," *IEEE Computer*, July 1979, p. 79.

linkage was made explicit in VHSIC, rather than being left to chance as in the by-product cases.

A prime example of a VHSIC spin-off is the development of digital signal processors (DSPs), and the current dominance of Texas Instruments (TI) in that market. DSP chips process vast amounts of real-world signals, including sound and images, into digital information in nanoseconds—far outstripping the capabilities of multipurpose microprocessors. Signal processing applications include digital motor controls, collision avoidance systems, and most significantly, all wireless computing and communications devices—cellular phones, pagers, personal digital assistants, and wireless modems. By 1998 DSPs were a \$4 billion business—only a 5 percent slice of the overall semiconductor market, but enjoying 40 percent annual growth rates.³²

As late as 1993, the market potential for DSPs was widely unappreciated.³³ But as early as 1978, digital signal processing had become the central focus of the VHSIC program. In contrast to the then-prevailing industry orientation that sacrificed high-speed signal processing for large-scale data processing, VHSIC planners quickly reached a consensus that signal processing should receive their primary, if not total, attention. Five of VHSIC's six major corporate contracts were directed to signal processing applications including high-speed processing of optical, acoustic, radar, and infrared signals.

One such award went to Texas Instruments in 1980 to develop the circuitry for a "fire and forget missile" that, once launched, could continue to process a rapid and continuous stream of incoming radar and infrared signals in homing in on a moving target. TI had dabbled in digital signal processing back in 1977 with the Speak and Spell toy that could recognize a word the moment a child finished spelling it. But it was the 1980 VHSIC award of \$23 million that provided the company with its high-end, leading-edge thrust in DSPs. TI has since reinvented itself from an all-purpose electronics supplier to a company centrally focused on DSPs. By 1998 DSPs accounted for 45 percent of TI's semiconductor sales, and the company held a commanding 45 percent world share in the DSP market.³⁴

32. "DSPs: The Shining Star in Weak IC Market," *Electronic Buyers' News*, October 28, 1996; "Industry Sees Limitless Future for Digital Signal Processors," *Wall Street Journal*, July 30, 1998; "Chips That Mimic the Human Senses," *Business Week*, November 30, 1998; and "No End in Sight to DSP Growth as Emerging Applications Beckon," *Electronic Buyers' News*, December 14, 1998.

33. "DSPs: The Shining Star."

34. "TI Bets Old Toy Chip Will Find Plenty of New Markets, Uses," *Wall Street Journal*, March 26, 1997; "Operating Earnings Up for Texas Instruments," *New York Times*, January 22, 1998; and "TI Sees Its Future in DSP," *Wired News*, July 29, 1998.

The Texas Instruments and digital signal processing story notwithstanding, VHSIC largely failed to realize the program's much anticipated commercial spillovers.³⁵ But the lack of more widespread spin-offs does not detract from the conceptual breakthrough represented by the effort. Reflecting the depth of VHSIC's initial intentional spin-off mode, ten of the top fifteen merchant semiconductor producers, representing 63 percent of the industry, participated in or sought involvement with VHSIC.

STRATEGIC COMPUTING

A second example of the intentional spin-off model was DARPA's ten-year, \$1 billion Strategic Computing Program.³⁶ Initiated in 1983, SCP quickly developed into DARPA's largest technology initiative, accounting for as much as one-third of the agency's budget. SCP sought to stimulate and integrate three major information technology fields: state-of-the-art very large scale integrated (VLSI) microelectronics; computer architectures for parallel processing wherein computers could operate thousands of processors simultaneously; and artificial intelligence research in such areas as computer-based problem solving, advanced vision systems, and speech recognition.

These research areas are obviously not specific to military applications. But as in the ARPANET and Sketchpad cases, these SCP investments are justified by DARPA's mission to pursue revolutionary technologies of potential military utility even if that means funding areas of generic value to both military and nonmilitary applications. But more in line with VHSIC than with ARPANET or Sketchpad, SCP organizers explicitly addressed the commercial implications of their research. The first SCP planning document spoke of how "spin-offs from a successful Strategic Computing Program will surge into our industrial community," and how "the value of future commercial products made available by development of the new generation technology will be enormous."³⁷

The most renowned commercial spin-off from SCP was the massively parallel computing field that exploded onto the scene in the late 1980s and early 1990s. Central to this story was Thinking Machines Corporation and its 64,000-

35. See Fong, *Federal Support for Industrial Technology*; and Fong, "The Future of Pentagon-Industry Collaboration."

36. Reed, Van Atta, and Deitchman, *DARPA Technical Accomplishments*, Vol. 1, chap. 21; Vol. 2, chaps. 14, 17; Norberg and O'Neill, *Transforming Computer Technology*, pp. 275–282; and Saul Amarel, "AI Research in DARPA's Strategic Computing Initiative," *IEEE Expert*, Vol. 6, No. 3 (June 1991), pp. 7–11.

37. Defense Advanced Research Projects Agency, "Strategic Computing: New Generation Computing Technology—A Strategic Plan for Its Development and Application to Critical Problems in Defense," October 28, 1983, p. 9.

processor Connection Machine (CM). In 1989 Thinking Machines won the coveted Gordon Bell Prize for top supercomputer performance. Two years later, *Business Week* profiled the company in a feature article, "Where No Computer Has Gone Before: Massively Parallel Processing Promises Unparalleled Performance."³⁸ At its height, Thinking Machines enjoyed \$65 million in annual sales, and attained the number two position in worldwide supercomputer sales. A Connection Machine even achieved celebrity status when it was prominently featured in the 1993 blockbuster *Jurassic Park*.

DARPA support for the company dates to 1979, when the agency funded the dissertation research of Thinking Machines future founder Danny Hillis. DARPA funded the fabrication of the first CM chips in 1980. In 1983 one of the first grants made by the Strategic Computing Program was a \$4.5 million award for the development of the Connection Machine. Thinking Machines was founded later that year, with the DARPA funds constituting the fledgling company's initial cash flow. A second SCP award for \$12 million was made in 1989 for the development of a second-generation product. Beside the two development grants, SCP also provided more than \$30 million in production subsidies to the company.³⁹

Thinking Machines went bankrupt in 1994. But descendants of its massively parallel processing architecture can now be found anywhere from dual-processor personal computers available at consumer electronics outlets to today's fastest supercomputers running hundreds, if not thousands, of processors simultaneously. A second-generation spin-off would also have to include Disney, which hired Hillis as vice president for R&D at Walt Disney Imagineering, the research labs of the studio.

Despite these commercial ramifications, the core of SCP—like VHSIC—remained mission oriented. In laying out the rationale for the program, DARPA organizers highlighted the severe constraints in meeting defense needs with the computing capabilities of the day. Advanced computing systems were needed to operate under conditions of critical time constraints, information overload, and environmental complexity and variability.⁴⁰ Hence the need to boost VLSI technology, parallel processing, and artificial intelligence. As im-

38. "Where No Computer Has Gone Before: Massively Parallel Processing Promises Unparalleled Performance," *Business Week*, November 25, 1991, p. 80.

39. Reed, Van Atta, and Deitchman, *DARPA Technical Accomplishments*, Vol. 2, chap. 17; Gary Taubes, "The Rise and Fall of Thinking Machines," *Inc.*, No. 3 (1995), pp. 61–65; and U.S. General Accounting Office, *High Performance Computing: Advanced Research Projects Agency Should Do More to Foster Program Goals*, GAO/IMTEC-93-24, May 17, 1993.

40. DARPA, "Strategic Computing Initiative," pp. i, ii; Reed, Van Atta, and Deitchman, *DARPA Technical Accomplishments*, Vol. 2, chap. 14, p. 24; and Amarel, "AI Research," pp. 8–9.

portant as they were to the program, these technologies represented means to achieve clear defense ends.

Indeed SCP was driven by a set of very specific military applications that demanded state-of-the-art machine intelligence. DARPA worked closely with the three military services to identify three such applications: (1) Autonomous Land Vehicle, an eight-wheeled robotic vehicle with image comprehension and independent navigation capabilities; (2) Pilot's Associate, an expert system on real-time internal and external flight conditions with spoken alerts and natural language interface; and (3) Naval Battle Management System, an expert and decision aid system for carrier fleet battlement management with natural language interface.⁴¹ This mission agency orientation was so controlling that segments of the academic community criticized the program for militarizing research in computer science.⁴² One does not have to take a position in this specific controversy to see that there is a potential for such distortion in intentional spin-off cases that give only secondary priority to civilian, commercial considerations.

Explicit Dual-Use Model

The strategic reorientation in U.S. industrial policy would deepen in the late 1980s with programs that would take on explicit dual-use characteristics. Programs for advanced lithography and high-performance computing, more than anticipating commercial spillovers in explicit spin-off fashion, would take the next step of programmatically developing commercial and industrial technologies. They would still pursue defense-related technologies, but would add equally important nonmilitary objectives to their agendas.

41. DARPA, "Strategic Computing Initiative," p. iv.

42. "Assessing the Strategic Computing Initiative," *High Technology*, April 1985; Terry Winograd, "Strategic Computing Research and the Universities," Silicon Valley Research Group, University of California, Santa Cruz, March 1987; Jonathan Jacky, "The Strategic Computing Program," and Lenny Siegel and John Markoff, "High Technology and the Emerging Dual Economy," both in David Bellin and Gary Chapman, eds., *Computers in Battle: Will They Work?* (Boston: Harcourt Brace, 1987), pp. 171–208 and pp. 259–282 respectively; Jay Stowsky, "From Spin-Off to Spin-On: Redefining the Military's Role in American Technology Development," in Wayne Sandholtz, Steven Vogel, John Zysman, Ken Conca, and Stowsky, *The Highest Stakes: The Economic Foundations of the Next Security System* (New York: Oxford University Press, 1992), pp. 133–135; and Paul N. Edwards, *The Closed World: Computers and the Politics of Discourse in Cold War America* (Cambridge, Mass.: MIT Press, 1996).

ADVANCED LITHOGRAPHY

One of the first (and still ongoing) technology initiatives to strike a more even balance between defense and commercial objectives was DARPA's Advanced Lithography Program. Lithography is the process used for printing circuits on silicon chips, and is the main technology driver for advances in microelectronics. The lithographic patterning of ever finer circuit lines, commonly measured in microns, is key to the miniaturization of ever more transistors on a chip and attendant advances in data capacity and circuit processing speeds.

Lithography is also the most challenging and costly process in the manufacturing of semiconductors, and DARPA has been aggressively supporting the technology for more than a decade. The agency began its first major program in 1988 when it targeted 0.25 micron circuit line-widths—a target representing a fourfold advance over the industry standard and a ten-year lead time ahead of projected industry production. In 1992 and 1996, DARPA would continue to push the technology down to 0.10 and 0.07 microns, respectively, with lead times prior to commercialization stretching to fifteen years. This program has been funded from \$25 million to \$75 million a year.⁴³

Three aspects of ALP illustrate its explicit dual-use characteristics. First, overt competitiveness concerns have been integral to DARPA's rationale for the program. Official documentation points to how ALP was needed to "aid industry against intense international competition." In forming the program, DARPA conducted a competitive analysis of seventy different organizations engaged in lithography R&D worldwide, including twenty-five Japanese and twenty European institutions. DARPA went so far as to ask, "Will the U.S., Germany, or Japan be first with the ultimate system?"⁴⁴

Second, DARPA highlights the need to "transfer" and "hand off" ALP results to the commercial U.S. industry.⁴⁵ With each of its pushes to smaller geometries, DARPA has laid out detailed technology road maps projecting the

43. David O. Patterson, "X-Ray Lithography Program" (Defense Advanced Research Projects Agency, 1989); Patterson, "X-Ray Lithography" (Defense Advanced Research Projects Agency, 1989); Lance A. Glasser, "The DARPA Advanced Lithography Program" (Defense Advanced Research Projects Agency, January 5, 1996). Prior to 1993, the effort was called the X-Ray Lithography Program.

44. Patterson, "X-Ray Lithography," pp. 6, 20.

45. Glasser, "The DARPA Advanced Lithography Program"; Patterson, "X-Ray Lithography"; Patterson, "X-Ray Lithography Program"; and Defense Advanced Research Projects Agency, "Modules for Lithography Systems for Design Rules of 0.18 Micrometers and Smaller," *Commerce Business Daily*, March 3, 1995, http://web-ext2.darpa.mil/ETO/Solicitations/CBD/cbd_9522.html.

transitioning of DARPA research into commercial production. As many as six sequential stages, stretching out as long as twenty years, would be broken out from initial DARPA research, to proof of principle demonstrations, to follow-up industry R&D, to industrial pilot line production, to early adoption decisions, and finally to full commercial production.⁴⁶ Such road maps are not always realized as originally cast. By nature, they are speculative and subject to change—in the case of lithography, they have recently become compressed or accelerated as advances have been achieved more quickly than anticipated. The point, however, is that DARPA takes great pains to explicitly program the dovetailing of its research with industrial commercialization.

Third, commercial considerations topped the list of selection criteria in the ALP request for proposals. Eight factors were listed as criteria for DARPA in making its award selections. Significantly the first two criteria were economic and commercial: the impact of the proposed R&D on the cost of industrial production; and the quality of the proposed business plan “for scale up to production quantities” and “marketing the product.”⁴⁷ Only after these commercial considerations came criteria such as technical merit, technical capabilities and qualifications, specificity of milestones, and cost realism.

The flip side of a dual-use program is, of course, its mission agency objectives. And in ALP, DARPA draws a straight line from lithography to lethality:

Advancements in lithographic technology are essential to exploit the military benefits to be derived from the use of semiconductors in essentially all defense systems. The development of faster, smaller computational and signal processing components manufactured through advanced lithographic processes offers opportunities in a variety of military systems, such as real time threat identification, target recognition, autonomous operation, surveillance, and smart sensors. New opportunities will arise with the advent of the digital soldier, who will require improved mobility and faster transmission of information to improve survivability, situational awareness, and lethality.⁴⁸

But reflecting a fundamental level of integration, DARPA stresses that ALP’s dual missions are virtually one and the same: “The DoD interests in lithography are intimately tied to the industry interests. There are some, but few, defense-unique requirements. . . . The Nation cannot afford, nor is it necessary to have, a defense-specific advanced lithography solution. DARPA’s Advanced Lithography Program is primarily a dual-use program.”⁴⁹

46. See Glasser, “The DARPA Advanced Lithography Program.”

47. DARPA, “Modules for Lithography Systems.”

48. DARPA web site, <http://web-ext2.darpa.mil/ETO/ALP/index.html>.

49. Glasser, “The DARPA Advanced Lithography Program,” p. 3.

Although ALP was one of the first programs to lead the explicit dual-use thrust, DARPA launched similarly oriented programs in such areas as high-definition television, high-temperature superconductivity, and artificial neural networks. Through the 1990s, DARPA devoted approximately half of its work to purely military-specific applications and the other half to dual-use technologies.⁵⁰

HIGH PERFORMANCE COMPUTING AND COMMUNICATIONS

One of the most prominent present-day explicit dual-use programs is the multiagency High Performance Computing and Communications Initiative.⁵¹ HPCC began in 1992 with a budget of \$654 million, some twenty times larger than ALP's. Since 1995 the program has grown to \$1 billion a year. This substantial investment is devoted to state-of-the-art R&D in supercomputers and advanced communications networking. The policy objectives behind this R&D are quintessentially dual use.

"Triple use" may be a more accurate phrase because HPCC is the product of three different agendas. First, HPCC is a direct follow-up to the Strategic Computing Program and encompasses the DoD's leading-edge mission agency R&D in computing. Second, HPCC incorporates the National Science Foundation's basic research in computing. Key NSF computing efforts supported by HPCC are its nationwide university supercomputing centers and its high-speed fiber optic communications networks. Third, HPCC was motivated by concerns over the competitiveness of the U.S. computer industry that emerged in the late 1980s. Two reports—one by the President's Office of Science and Technology Policy in 1987, the other by the National Academy of Sciences in 1988—warned of growing competition from Europe and Japan in supercomputers and computer networking, and called for a national strategy to strengthen the U.S. position. These concerns were taken up in Congress, and were combined with the interests of the academic and military communities in

50. Jeffrey F. Rayport, "DARPA," Harvard Business School Case 9-390-142 (Boston: Harvard Business School, February 14, 1990); Harvey Simon, "DARPA and High Definition Systems: For Home or For War?" Harvard Kennedy School of Government Case, C16-90-942.0, 1990; U.S. Library of Congress, Congressional Research Service, "The Defense Advanced Research Projects Agency: DARPA," 93-27 SPR, January 15, 1993; U.S. Library of Congress, Congressional Research Service, "Is DOD the Place to Fund Dual-Use Technology?" 93-496 SRP, May 17, 1993. In this one instance, the dual-use term is used in accordance with common parlance rather than the narrower definition used elsewhere in this article.

51. Beginning in 1998, the HPCC program was renamed the Computing, Information, and Communications (CIC) program.

the enactment of the High Performance Computing and National Research and Education Network Act of 1991.⁵²

Not by coincidence, the first HPCC mission statement cited three broad goals: (1) extend U.S. leadership in high performance computing and networking technologies; (2) apply the technologies to the economy, national security, education, and the environment; and (3) “spur gains in U.S. productivity and industrial competitiveness.”⁵³ The first two goals address the traditional arenas of government R&D support: basic research and mission agency R&D. The third aim is the clearest statement yet of the economic relevance of a technology program. Unlike the intentional spin-off cases, commercial considerations received comparable attention to military intentions in the formulation of HPCC.

HPCC’s technical agenda is differentiated between a series of “grand challenges” and “national challenges.” Although both are a series of computing-intensive applications used to drive the program’s research, they reflect different program objectives. Grand challenges tend to be made up of scientific investigations or mission agency R&D projects such as gene research, digital anatomy, ocean modeling, ozone depletion, weather modeling, and planet imaging. In contrast, national challenges such as electronic commerce, information infrastructure services, manufacturing process modeling, and semiconductor manufacturing are more directly relevant to economic competitiveness.

In 1993 the Clinton administration further enhanced HPCC’s economic dimension with the addition of a new program element called Information Infrastructure Technology and Applications. IITA programmed 25 percent of the HPCC budget and served as the R&D foundation for the administration’s broader information superhighway initiative—itsself an effort to bolster the competitiveness of the U.S. economy.⁵⁴

Although not as prominent as in the by-product and intentional spin-off cases, defense interests are still significant in HPCC. Not only is DARPA one of the program’s twelve participating federal agencies, but that agency has had the largest HPCC budget among the twelve. Indeed DARPA accounts for one-

52. Hart, Reed, and Bar, “The Building of the Internet.”

53. Committee on Physical, Mathematical, and Engineering Sciences, *Grand Challenges: High Performance Computing and Communications* (Federal Coordinating Council for Science, Engineering, and Technology [FCCSET], 1992), p. 3.

54. National Research Council, *Evolving the High Performance Computing and Communications Initiative to Support the Nation’s Information Infrastructure* (Washington, D.C.: National Academy Press, 1995); and Committee on Physical, Mathematical, and Engineering Sciences, *High Performance Computing and Communications: Toward a National Information Infrastructure* (FCCSET, 1994).

third of HPCC funding, and its \$300 million share represents a tripling of the Strategic Computing Program budgets. Together with the defense-oriented research of the Department of Energy, up to 40 percent of HPCC funding is military related. Mission agency R&D is alive and well in HPCC, albeit in a balanced dual-use setting.

Industrial Base Model

With Sematech in 1987 and the National Flat Panel Display Initiative in 1994, U.S. industrial policy would take on industrial base features. Going a step further than the even balancing of military and commercial technology objectives in the explicit dual-use model, Sematech and NFPDI tip the scales in favor of commercial technology agendas.

SEMATECH

Established in 1987, Sematech was the first major program to innovate the industrial base model outside of wartime conditions. Originally a consortium of a dozen leading U.S. chip makers, Sematech conducts and sponsors R&D in semiconductor manufacturing technology. Until 1997 half of Sematech's \$200 million annual budget was funded by DARPA, and the agency had a formal seat on the consortium's board of directors. Since then, Sematech has been financed solely by its member companies, including new foreign members.⁵⁵

It is instructive to center this discussion around a 1995 Sematech mission statement. Although in line with other mission statements including those issued by Sematech itself, this particular version was published by DARPA. As such it provides insight into how the agency perceived its relationship with the consortium—striking at the core of the civilian-military issues that motivate this analysis. The statement in its entirety reads:

The mission of SEMATECH is to solve the technical challenges required to keep the United States number one in the global semiconductor industry. SEMATECH develops advanced semiconductor manufacturing tools and technologies to accelerate the transition of advanced processing technology to the domestic semiconductor industrial base. SEMATECH addresses key issues throughout the semiconductor manufacturing food chain, thereby assuring DOD access to a domestic semiconductor manufacturing industry. SEMATECH will enable the cost effective manufacture of leading ICs [inte-

55. The following analysis applies only to the 1987–97 period of partial federal funding and U.S.-only membership.

grated circuits], scalable for any production volume. The program is also introducing manufacturing processes that are environmentally conscious and improve the health and safety of manufacturing personnel. SEMATECH aims to provide its participants with the lowest cost production of leading semiconductor products, ensure access to a competitive supplier infrastructure and flexible manufacturing capabilities, and to develop a research and education infrastructure necessary for sustained U.S. leadership in semiconductor technology.⁵⁶

This brief statement reflects the fundamental logic of the industrial base model. The statement begins and ends with Sematech's overt commercial objective of maintaining U.S. leadership in the global semiconductor industry. Between 1978 and 1988, the share of the world semiconductor market held by U.S. producers declined from almost 60 percent to less than 40 percent, with the Japanese taking over the number one position in 1986. Sematech was explicitly formed to reverse these trends. This commercial focus is reinforced in the main body of the DARPA statement that emphasizes not only manufacturing and production technologies, but also the transitioning of those results into industry and into product. No unstructured basic research here.

Not insignificantly, these Sematech priorities mirror the semiconductor initiatives sponsored by Japan's Ministry of International Trade and Industry (MITI). Attaining semiconductor leadership for Japan has been a long-standing MITI objective. For instance, MITI's most recent semiconductor initiative—the five-year, \$500 million Association of Super-Advanced Electronics Technology (ASET) project announced in 1996—was a response to the erosion of the technological and competitive position of Japan's chip industry in the 1990s, just as Sematech was a response to U.S. adversities a decade earlier. And akin to Sematech's manufacturing and industrial focus, Japan's efforts such as ASET have traditionally focused on industrially relevant technology rather than basic science.⁵⁷ Conceptually, Sematech has more in common with Japanese industrial policy programs than it does with the other U.S. programs reviewed thus far.

When DARPA does refer to Sematech's noncommercial defense relevance, embedded in the middle of the mission statement, it does so in a passing manner in the middle of the statement. Even though this statement came from DARPA rather than Sematech, and despite DoD financing 50 percent of the

56. DARPA web site, <http://esc.sysplan.com/ESTO/SEMATEC/index.html>. Last updated: September 18, 1995. With the end of government funding for Sematech, this web page has been removed from the DARPA server.

57. See Fong, "Follower at the Frontier."

consortium's budget. Far from claiming 50 percent of the consortium's attention, Sematech's defense mission was distinctly overshadowed by its competitiveness and industrial agendas. Although technically a dual-use program, one use clearly dominated the other.

Although secondary from a broader Sematech context, the stated DoD need for access to the semiconductor industry is indeed a vital issue for the military. At stake is the military's secure and reliable access to leading-edge semiconductor technology to be utilized in defense communications and weapons systems. Although DoD interest in leading-edge technology is nothing new, and motivates the department's support of all the cases discussed thus far, Sematech is distinctive for how DoD went about gaining such access in ways not unlike a Japanese MITI program.

The rationale for such extraordinary measures grew out of DoD's concerns over the state of the U.S. semiconductor industry in the 1980s. In a 1987 report, DoD warned that the competitive and technological decline of the U.S. industry had led to heightened dependency of defense systems on foreign semiconductor components. Deeming such foreign dependency unacceptable, the Pentagon outlined a program for the revival of the U.S. industry, a program that would take shape as Sematech.⁵⁸

In short, if DoD needed access to this industry, it needed an industry to have access to. Hence the investment in the buildup and maintenance of a world-class semiconductor industry. Such is the core of the industrial base model—programs with primarily commercial objectives that, in the Sematech case, also have secondary (but not unimportant) military benefits.

FLAT PANEL DISPLAYS

In 1993 the Clinton administration held up Sematech "as a model for federal consortia to advance other critical technologies."⁵⁹ R&D in flat panel displays (FPDs) presented a first opportunity to extend the model. FPDs produce images by sandwiching a thin layer of chemicals and/or electronics between two layers of glass or plastic. With sharper resolution, and half the depth, weight, and power requirements of conventional cathode-ray picture tubes, FPDs are poised to move beyond their major consumer application in laptop computers to desktop computers, television monitors, and large presentation screens.

58. Office of the Undersecretary of Defense for Acquisition, *Report of the Defense Science Board Task Force on Defense Semiconductor Dependency*, February 1987.

59. William J. Clinton and Albert Gore, Jr., *Technology for America's Economic Growth: A New Direction to Build Economic Strength*, February 22, 1993, p. 9.

In a market dominated by Asian producers, U.S. FPD manufacturers have held only a 3 percent world market share. To boost that position, and possibly leapfrog the competition, the National Flat Panel Display Initiative was established in 1994 and funded at \$370 million through 1998. NFPDI supported three different display technologies (liquid crystal, electroluminescent, and field emission) as well as the development of equipment and materials necessary for display production. Some seventy different companies and research institutions were affiliated with the program.

At first glance, the flat panel initiative might appear to be a straightforward defense technology program. The program was entirely funded and managed by DoD, and NFPDI-sponsored displays have been incorporated into the Apache attack helicopter, the F-16 Falcon, and the Abrams M1A2 tank. Pentagon officials have even explicitly disassociated the program from “a heavy-handed industrial policy.”⁶⁰

Semantics (and real-world political concerns) aside, two distinctive features definitively establish not only NFPDI's explicit dual-use characteristics but its Sematech-inspired industrial base grounding. With regard to the former, NFPDI was a product of the merging of DoD interests and high-level White House policy in the Clinton administration. The DoD interest was fundamentally mission oriented:

As Desert Storm demonstrated in a dramatic and compelling fashion, our armed services are rapidly moving into an era in which information is the primary currency used to secure both tactical and strategic military advantage, save lives, and reduce material losses. A virtual torrent of digital data—from myriad air, sea, ground surveillance systems, orbiting space sensors, specialized remote probes, intelligence sources, digital mapping databases, and a proliferating array of new sources—will have to be fused together and presented to a combatant in ways that permit fast and effective real-time responses on the front line. . . . Visual displays are the primary interface between those making time-critical military decisions and their information resources, showing both information gathered by sophisticated sensors and text and graphical data required for optimal mission performance. . . . The outcomes of future conflicts will be increasingly decided by the quality and effectiveness of the information resources utilized by our forces.⁶¹

In contrast, the White House was interested in the broader strategic economic value of flat panel displays. The future competitiveness of the U.S. com-

60. Kenneth S. Flamm, “Flat-Panel Displays: Catalyzing a U.S. Industry,” *Issues in Science and Technology*, Vol. 11, No. 1 (Fall 1994), p. 27.

61. “Building U.S. Capability in Flat Panel Displays,” report of the Flat Panel Display Task Force, September 1994, chap. 1, p. 3.

puter, telecommunications, semiconductor, and other electronics industries was “linked” to having a robust domestic FPD industry.⁶² Indeed, White House officials looked to the NFPDI as a “model of technological development” that could be employed for other civilian technology initiatives in such areas as robotics, ceramics, electronic packaging, lithography, and micro-electromechanical systems. For the White House, NFPDI served as a case study in how to advance the position of U.S. companies worldwide in high-technology markets.⁶³ These military and economic agendas were institutionally fused in the 1994 interagency task force that drew up the flat panel initiative—a task force that included officials from the White House National Economic Council, Council of Economic Advisors, Office of Science and Technology Policy, Department of Commerce (DoC), United States Trade Representative (USTR), as well as DoD.

NFPDI’s industrial base characteristics were revealed in the very deliberations of this interagency task force as well as in the substance of the initiative itself. In formulating its recommendations, the task force undertook a comprehensive analysis of eleven alternative FPD technologies; estimated future demand of flat panels into the twenty-first century, broken down by specific product markets; conducted a competitive assessment of foreign FPD production capacity not just by country but down to specific manufacturers; critically analyzed the industrial strategies of the U.S. industry including individual equipment and material suppliers, computer manufacturers, and U.S. display producers; assessed the economics of FPD production; calculated the economic barriers to entry for U.S. producers in terms of cost of operations and risk of investment; and surveyed foreign government FPD policies in Asia and Europe. One could hardly imagine a more thorough preparation by Japan’s MITI.

The task force then laid out a multifaceted and coordinated set of proposals that included Department of Energy as well as DARPA R&D investments; the coordination and promotion of procurements of FPDs across the entire federal government; DoC export promotion programs for FPD; FPDs as a priority in USTR foreign market access efforts; the rationalization of U.S. tariffs on products related to FPD production; international technology transfer agreements to access foreign FPD technologies; and a DoC/USTR-led interagency office to conduct competitive analyses of world flat panel display markets. The extra-DoD components of this program make it abundantly clear that NFPDI was

62. *Ibid.*, chap. 1, p. 6.

63. Claude Barfield, “Flat Panels Displays: A Second Look,” *Issues in Science and Technology*, Vol. 11, No. 2 (Winter 1994–95), p. 22; and interview materials.

meant to be much more than a defense technology program that happened to carry dual-use potential for commercial applications. Instead, military R&D in flat panels was embedded within a much broader national strategy. More than a technology program, and more similar to Sematech, NFPDI sought nothing less than to “foster the creation of a viable domestic industry that is competitive in global markets.”⁶⁴

The task force identified a 15 percent U.S. share of the world FPD market as a programmatic target for the year 2000. Given that the United States held only a 3 percent world market share in 1994, the initiative envisioned a fivefold increase in relative production (many times more in absolute production). Such visions are more akin to strategic plans formulated and carried out by Japan’s MITI or other examples of the East Asian developmental state model. In seeking to create an industry where one almost did not exist, NFPDI even exceeds the Sematech goals of reviving a troubled but well-established industry.

Many of the non-DoD aspects of the task force’s plan were not implemented. But what remained of the initiative retained important industrial base characteristics. First, DARPA made R&D awards with a special emphasis on FPD manufacturing technology. Included here is support for the U.S. Display Consortium. With an annual budget of \$25 million, USDC is a team of fourteen display developers working with more than 100 suppliers to develop next-generation manufacturing process equipment and materials for flat panel production.⁶⁵ The emphasis here is on developing manufacturing capabilities, not just lab work with dual-use potential. Second, \$50 million investments, matched by the industry participants, were made in two manufacturing test sites. These pilot production lines produced displays in limited quantities to test new manufacturing equipment and processing techniques, and help move the industry up manufacturing learning curves. Third, \$50 million in R&D grants was awarded to companies as an incentive to move into high-volume FPD manufacturing. Recipients had to match the government funds with internal corporate R&D funding, and then match the government again with corporate financial commitments to establish volume production facilities. These awards were made to sixteen companies organized into three separate joint ventures.

These three program thrusts move NFPDI squarely into the industrial base category. By DoD’s own estimates, U.S. military demand for FPDs would amount at most to 5 percent of the world market—or only one-third of the 15

64. “Building U.S. Capability,” 1994, chap. 1, p. 2.

65. United States Display Consortium, *Corporate Report*, 1998; and web site, <http://www.usdc.org>.

percent world market share contemplated by the initiative. The 2:1 ratio is a good indicator of the balance between commercial and military agendas at play in this program.

The one-third stake of DoD is a reminder that the NFPDI is still not a pure civilian industrial policy program. The Pentagon's interest in a robust commercial FPD industry, as in the semiconductor industry case, is as a secure source of technologically leading-edge products at affordable prices. It is true that in NFPDI as well as Sematech the military was to be a secondary beneficiary of the commercial industry it sought to build or rebuild. But the defense hook is still there. And although these programs are primarily commercially oriented, they are still being undertaken by a defense agency.

Economic Competitiveness Model

The Advanced Technology Program is the only one of the nine cases that would qualify as a bona fide civilian industrial policy initiative. ATP promotes commercializable technology and is therefore not associated with the tradition of government investment in basic research. The program is also completely outside of the military R&D apparatus. Operating within the Department of Commerce, ATP is not associated with any historic mission-oriented R&D—including the science-based standards-setting mission of the Commerce Department's National Institute of Standards and Technology. ATP represents the leading edge of the strategic reorientation in U.S. technology and industrial policy in support of national economic competitiveness.

The Omnibus Trade and Competitiveness Act of 1988 authorized the ATP to work with U.S. industry "to advance the nation's competitiveness" by helping to fund the development of high-risk technologies that could "enable new applications, commercial products, and services."⁶⁶ This act has been described as probably the most important example of how international competitive pressures have led to explicit policies aimed at improving the performance of U.S. industries.⁶⁷

Since its inception, ATP has awarded \$1.5 billion in technology grants (not including matching amounts from the awardees) to more than 1,000 companies and research institutions. Awarded on the basis of rigorous, selective com-

66. U.S. Department of Commerce, "Advanced Technology Program: A Guide for Program Ideas," April 1994, p. 1.

67. Loren Yager and Rachel Schmidt, *The Advanced Technology Program: A Case Study in Federal Technology Policy* (Washington, D.C.: American Enterprise Institute, 1997), p. 9.

petitions (only 15 percent of proposals are selected), successful ATP bidders must demonstrate the scientific and technical merit of their proposed projects. But commensurate with the broader economic agenda of the program, ATP winners must also demonstrate the business and economic merit of the proposed R&D. Indeed ATP's selection criteria give 50 percent weightings to technical merit and economic merit.⁶⁸

To advance its economic objectives, ATP requires bidders to submit the equivalent of a business plan for evaluation. The plans must outline a credible commercialization strategy, including rough timetables, for bringing new technology to market. Moreover, they must elaborate how the broader national economy will benefit from the proposed technology—for instance, in terms of industrial capability, productivity gains, interindustry linkages, jobs, sales, exports, economic growth, and rising standard of living. As highlighted by the Department of Commerce, “the whole point of the Advanced Technology Program is to foster significant economic benefits for the country.”⁶⁹ ATP is therefore as much an economic policy instrument as it is a technology program.

Although ATP is this article's lone case of the economic competitiveness model, the program actually constitutes a series of targeted initiatives in selected technology areas. From 1994 to 1999, ATP slated three-quarters of its budget for a number of “focused programs” where \$50–\$100 million each was devoted to specific technical areas over three- to five-year periods. Of the seventeen focused programs funded, approximately half are IT-related including those for component-based software, digital data storage, digital video in information networks, microelectronics manufacturing, and photonics manufacturing.

The Digital Data Storage program typifies the economic competitiveness objectives behind these initiatives. Mass digital data storage has been labeled the vital “parking lots” along the side of the information superhighway. As the ability to move huge files and full-motion video across the internet is enhanced, so too is the need for making downloads to high-capacity storage devices. In 1995, ATP launched a \$100 million program in this technology. Awards have been made to more than a dozen companies to develop next-generation magnetic tape and optical disk hardware and software.

After noting “lost market shares” to foreign digital storage competitors, ATP set the objective of this focused program at nothing less than “U.S. predomi-

68. U.S. Department of Commerce, *Advanced Technology Program Proposal Preparation Kit*, November 1999.

69. U.S. Department of Commerce, “Advanced Technology Program,” p. 3.

nance in the high-performance digital data storage market over the next decade." By promoting 60 percent annual improvements in storage capacity and performance, the program is designed to help U.S. industry "pull away from the global pack." ATP warns that unless the United States protects its investment in this technology, the country risks "the loss of not only the data storage industry, but the computer industry as well."⁷⁰ At stake in this and other ATP focused programs is more than just advanced technology. Instead market shares, economic growth, and industrial predominance or demise are professed to be at stake.

When ATP was first funded in 1990 it had a \$10 million budget, and its budget would rise to \$68 million under the Bush administration. In 1993 the Clinton administration embraced ATP as the centerpiece of its civilian technology policy with intentions of transforming it into the civilian equivalent of DARPA.⁷¹ The budget was promptly boosted to \$200 million, and the administration has submitted budget projections to the year 2003 that raise ATP funding to \$400 million. Depending upon the perspective, ATP goes the furthest in breaking new ground or breaking the rules for U.S. technology and industrial policy.

Conclusions

This analysis of nine major U.S. technology programs has important implications for both security studies and assessments of technology and industrial policymaking in the United States. For security studies, the interface between defense technology programs and civilian, commercial technology is clarified. That interface is not uniform, and has been broken out across the first four of five policy models: by-product, intentional spin-off, explicit dual-use, and industrial base. The differentiated intent of DoD technology programs highlighted in this typology is largely blurred in the general literature on dual-use technology and military spin-offs.

This blurring of distinctions can lead to both unfair and inflated assessments of defense technology programs. It is self-evident that Pentagon programs should not be assessed against criteria they were never designed to meet. Yet

70. U.S. Department of Commerce, "Digital Data Storage," ATP Focused Program 97-04, February 1997, pp. 2-5.

71. Clinton and Gore, *Technology for America's Economic Growth*; Office of the Press Secretary, White House, "Press Briefing by Assistant to the President for Science and Technology Policy Dr. John Gibbons and Deputy Assistant to the President for Economic Policy Bowman Cutter," February 23, 1993; and interview materials.

this is exactly what happens when a critic of, for instance, VHSIC or the Strategic Computing Program, makes the charge that DoD failed to contribute to the competitiveness of the U.S. semiconductor or computer industries. Such charges, although empirically valid, are analytically misdirected because of the secondary priority given to competitiveness concerns in intentional spin-off cases. Clearly the standards of one model should not be applied to programs that fall under an altogether different model. Programs have their deficiencies, of course, but they should be gauged against their own stated objectives.

Conversely, it is a mistake to give too much credit to defense programs such as ARPANET and Sketchpad. While the implications of these programs are widely recognized, including in this analysis, they are largely unintended consequences. In these by-product cases, program managers should not be credited for developments that they never anticipated, let alone engineered. Although this article does not (and could not, because of space considerations) assess any of the cases in terms of their technological or economic outcomes, the typology offered here provides important guidance for identifying the proper criteria for program assessment.

More broadly, this analysis makes important contributions to assessments of technology and industrial policymaking in the United States. The nine cases demonstrate an increasing capability of the United States to undertake programs directly relevant to economic competitiveness. This reorientation has taken place incrementally and not without controversy or reversals. For instance, beginning in 1995, many of these programs faced congressional budget cuts. Particularly targeted for cutbacks were programs in the last three categories of explicit dual-use, industrial base, and economic competitiveness, in large part because these programs have deviated the furthest from the traditional postwar technology policy and broader *laissez-faire* paradigms.

But the ALP and HPCC explicit dual-use programs not only survived any cuts, but in the latter case, enjoyed a 25 percent funding increase in fiscal year 2000, and is slated for a 36 percent boost in FY2001. Moreover, the explicit dual-use logic has been replicated in the five-year, \$500 million Next Generation Internet Initiative (1996–2000), and the ten-year, \$1 billion Accelerated Strategic Computing Initiative (1996–2005). The first program is funding R&D on networking infrastructure operating at speeds 100 to 1,000 times faster than the current internet, while the second program is developing supercomputers operating at a trillion or more operations a second. DARPA has also launched new explicit dual-use efforts in optoelectronics, microelectromechanical systems, and molecular electronics.

Although Sematech weaned itself off federal support after nine years, and even though budget cuts truncated the flat panel initiative, the industrial base logic was extended to the five-year, \$400 million Electronic Packaging and Interconnect Program to help bring multichip modules into the mainstream of the semiconductor industry. And DARPA's ALP has increasingly taken on attributes of an industrial base program, building up domestic manufacturing capabilities for advanced lithography toolmaking.⁷²

Because ATP can be viewed as going the furthest in "breaking the rules," the program was threatened with congressional elimination in 1995 and 1996. Although still a target of budget cuts, for four years running (1997–2000), ATP has received majority votes in Congress with annual budgets of approximately \$200 million. Moreover, ATP's economic competitiveness logic has been extended to three other programs: (1) the Manufacturing Extension Partnership, a national network of some seventy centers to diffuse new technologies to small and medium-sized manufacturers; (2) the Partnership for a New Generation of Vehicles, a joint venture with the Big Three automakers to help develop a "supercar" by 2004 with triple the fuel efficiency of today's vehicles; and (3) the AMTEX Partnership, a program with the textile industry to help move this troubled low-tech sector to a higher technological plane.

The latest evidence of this reorientation is the National Nanotechnology Initiative. Announced in January 2000, the \$500 million a year initiative focuses on the science and engineering of manipulating and moving matter at the atomic level—with the attendant potential for revolutionizing the way almost all materials and products are designed and manufactured. While traditional basic research and national security interests are fundamental to this effort, commercial and industrial benefits are also prominently featured, including: (1) radically transforming industrial processes with "bottom-up manufacturing" at the nanometer level; (2) developing materials with ten times the strength of steel but at a fraction of the weight, for ground, sea, air, and space vehicles; and (3) vastly shrinking the size of integrated circuits and mass storage devices while enhancing their speed and capacity up to a millionfold.

This evidence of a strategic reorientation in policy objectives, or even the mere differentiation across the cases, stands in direct contrast to the dictates of the postwar paradigm that restricted government R&D programs to either basic research or mission agency R&D. The results also stand in contrast to the

72. Specific thanks to Richard Van Atta for highlighting this point.

broader literature that has highlighted the constraints on U.S. technology and industrial policy programs from addressing issues of economic competitiveness.

Subsequent work with respect to other structural dimensions of U.S. industrial policymaking will evidence corresponding movement. With respect to policy instruments, the same nine cases manifest trends toward more substantial investments of financial resources and more nuanced forms of government-industry collaboration. Regarding state structure, the cases demonstrate movement toward improved levels of interagency coordination and coherence. With respect to state autonomy, the cases reveal levels of strategic policymaking insulated from immediate political pressures. And with regard to policy networks, the evidence points to the institutionalization and utilization of new government-industry linkages in support of policy design and implementation.

Progress along each of these structural dimensions, however, would be for naught if the overall policy orientation of the government were misdirected. The most coherent, autonomous state with a vast array of effective policy instruments and supported by well-institutionalized policy networks would contribute little to national economic competitiveness if it deployed its resources for ends unassociated with or contrary to competitiveness. In this context, the strategic reorientation in policy objectives is a defining requisite for U.S. industrial policymaking.