Big Science, Competitiveness, and the Great Chain of Being

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During the 1980s in the United States, issues of Big Science and national competitiveness became entwined as advocates of Big Science projects increasingly sought to justify them to patrons in the White House and Congress in terms of competitiveness. I shall examine this aspect of U.S. public policy and what it has to say about the discourses on Big Science and competitiveness, discourses in which to a large extent the role of technology has been treated as unproblematic and in certain ways as invisible. I shall therefore also touch upon changing ideas among policymakers and those who spend government money on the appropriate role of government in technological innovation.[1] In particular, I shall point to the continued exploitation of the "technology as applied science" model despite the fact that the underpinnings of the model have long been exploded by historians of technology.

Definitions

But to clear the ground for the later discussion, I turn first to the issue of definitions. Both of the terms in the title of the chapter have come to assume a wide, often muddied, and still shifting set of meanings. A recent report by the Office of Technology Assessment, for example, notes that Big Science "can mean large and expensive facilities. It can refer to large, multidisciplinary team efforts that entail cooperative planning and therefore require individual scientists to sacrifice some freedom in choosing goals and methods. Or it can refer to bureaucratic central management by government administrators."[2] The common equation of Big Science—that big bucks plus a big machine equals Big Science—is also flawed. Users of very expensive and big machines can certainly work in the spirit of small-scale science. For example, in the case of the International Ultraviolet Explorer, an international astronomical satellite launched in 1977 that cost well over $100 million to build, the users have to a very large degree followed the methods of small-scale science. A definition of Big Science that centers on money *and* scientific and technical practice is therefore a much more useful historical tool.[3] Of course, not only has Big Science implied somewhat different things to different users of the term, but it has also taken on different meanings at different times. When a historical actor of the late 1960s refers to Big Science, he or she is not referring to the same historical phenomenon as a historical actor of the early 1990s.

With these warnings in mind and for the purposes of this chapter, I shall take Big Science to mean very expensive projects that are directed toward the production of scientific results and that involve large multidisciplinary teams, not only for the building of the technologies for Big Science but also their use. In Big Science, the design and construction of the technologies that make the science possible have been very largely the task of industrial contractors. Their resources and expertise have indeed generally been essential. The costs of Big Science are also so high that the federal government has almost invariably been the sponsor of such endeavors. Designing, building, and funding the tools of Big Science have thus engaged the horizontal association or cooperation of different sectors of society: government, industry, and academe.

As seen in other papers in this volume, the meaning and use of the word "competitiveness" has also shifted, as has its rhetorical power. National, or industrial, or technological competitiveness have taken on a variety of meanings in their employment by economists, public officials, and others. Competitiveness has thus proved an elusive concept that cannot be reduced to any one variable. There is, nevertheless, a growing agreement among economists that an industry or firm is competitive if it is capable of maintaining its share of existing markets or of conquering new ones.

At this point it is also worth emphasizing that it is only quite recently that technology has begun to find a place in economists' analyses of international trade. The previous dominant approach was that of those who dealt with competitiveness in terms of wage and price rates. Neoclassical theory claimed that technological differences could be understood by so-called production factors that were taken to be identical throughout the world, and so in this way technology, in effect, disappeared.[4] Some economists, however, have more recently taken a very different tack. François Chesnais, for example, stresses the role of the state in the constitution and maintenance of a national productive system: "This structure is based on the technical system (a concept developed by Bertrand Gille), a key factor in the determination of inter-industry relations. In this network of interdependencies, the manufacturing of industrial machinery determines the structural base of competitive national economies."[5]

The Great Chain of Being

The two terms, Big Science and competitiveness, have been widely and explicitly linked in the last decade. Those doing the linking have claimed or accepted that the pursuit of various Big Science projects increases competitiveness. For example, in the recent debates on whether or not the federal government should support the Superconducting Supercollider—a multibillion-dollar high-energy physics accelerator—the project has been portrayed by advocates in the executive branch, the congress, and the scientific community as an investment in industrial competitiveness. Such debates have now taken on a particular edge for two reasons. First, such Big Science projects have been slated to absorb large chunks of the new discretionary spending in the federal budget. Second, these machines and systems have become for many Americans *the* symbols of the cutting edge of American technology, surrogates for national technical prowess.[6] In 1989, during the House floor debate on the Superconducting Supercollider, one representative termed it an "investment in the new wealth of tomorrow." Another, anxious about Japanese gains in high technology, called the Supercollider "an opportunity to gain that technology back," while a colleague urged "Vote yes for America's future."[7] When the Mayor of Waxahachie, Texas—the site of the Superconducting Supercollider—tells us of mankind's need to find out whether or not an exotic subatomic particle such as the Higgs boson exists, we can legitimately question the sincerity of the claim.[8] But while some of these claims are paper-thin disguises for pork-barrel politics, surely the same cannot be said for all of them.

Such demands and pleas for major national investments in Big Science enterprises, when meant seriously, immediately engage the debate over the relationship between science and technology. Historians of technology have long dismissed the vision of technology as merely applied science, and have generally embraced the view of technology as knowledge instead. In his excellent 1985 review of the relationship between science and technology, George Wise made particular reference to a 1972 meeting at the Burndy Library, the proceedings of which were published four years later in *Technology and Culture*. This meeting, Wise argued, was an extended "funeral" for the old technology-as-applied-science view.[9]

But such a view has been a central justification for the federal support of science since World War II and it has proved extremely robust. One image it conjures up is of a pool of scientific knowledge from which those who thirst after technological innovations can drink. Adding new knowledge to the pool increases the chances of additional technological advances.[10] I am of course not denying that science can be immensely important for new technologies. As, for example, Braun and McDonald argued in *Revolution in Miniature*, "the technology of semiconductor electronics is distinguished by its very great dependence on science. Perhaps more than any other innovation, modern electronics owes its existence to science; it is truly an innovation based on science."[11] What historians of technology do dispute is the notion that basic science runs naturally and in an orderly way to applied science and thence to development and commercial applications, and that the process is somehow inevitable. George Wise characterized this vision of the relationship between basic science and technology as the assembly line model. It is also the argument that Derek deSolla Price derisively referred to as the great chain of being. Later in the chapter I shall draw together some of the criticisms made of this argument.

The Promotion of Technology

In order to provide a context for the later discussion, I shall first sketch briefly the changing ideas on the federal government's role in the promotion of novel technology. In the late 1940s, the major figures and framers of federal postwar science and technology policy felt little need to push innovation and commercialization. Neither the Bush Report nor the Truman administration's 1947 Steelman Report paid much attention to industrial innovation. The Steelman Report was nevertheless closer to New Deal political thinking than the more famous Bush Report. Even so it envisaged only a limited role for government.[12] As Bruce Smith has argued, it called for constant innovation so that American industry could keep ahead of growing foreign competition. How was this to be accomplished? The answer was "by making sure the United States maintained overall scientific and technological leadership through a strong effort in basic and applied research and the education of high-quality scientists and engineers. Market forces would ensure that research resulted in products, economic growth, and jobs. Entrepreneurs rather than government planners should guide investment."[13] America's industrial history, it was argued, showed that the economy would generate innovations fast enough without the need for explicit policies. For policymakers in the late 1940s, as Harvey Brooks has expressed it, "technology was essentially the application of leading-edge science and that, if the country created and sustained a first-class science establishment based primarily in the universities, new technology for national security, economic growth, job creation, and social welfare would be generated almost automatically without explicit policy attention to all the other complementary aspects of innovation."[14]

Although there were various special cases before the early 1960s, the first really broad efforts to foster the commercialization of civilian technology as a matter of public policy started in the early 1960s in the Kennedy administration. Disturbed by a sluggish economy, in the summer of 1962 Kennedy established a Cabinet Committee on Growth. At the time, the president's science advisers were examining the same issues. The major conclusions of the two groups were very similar. In their opinion, the mechanism of the marketplace had successfully fostered innovation, but flaws in the market were becoming apparent. As Smith has noted:

> Some firms were portrayed as short-sighted and lacking the expertise to estimate the benefits of investing in new technologies. Others could make accurate, short-run benefit-cost calculations but could not take into account industry wide or society wide effects that would come from the adoption of new processes or products. This problem was exacerbated because the federal government, by monopolizing many of the nation's best scientists and engineers in the defense and space programs, diminished the pool of talent available to civil technology. Committing resources to research and development in defense and space science was appropriate but contributed little directly to economic growth. More efforts were therefore needed to stimulate civilian technology and expand the pool of talent so that the government's own programs would not be a brake on economic expansion.[15]

(As an aside, it is worth noting that while the reports differed a little, they did agree that the needs of defense and civil technology were in conflict.)

To address these perceived problems, the administration formed the Civilian Industrial Technology program, the first of many government initiatives to stimulate innovation in the civilian economy. The program, however, was defeated in the Congress by the very industries it was supposed to help. But it was, after modifications, reborn in the Johnson administration as the State Technical Services Act, in which guise it emphasized the exchange of technical information and consultation among industry, the universities, and state governments.[16]

There were other, related efforts during the Kennedy and Johnson Administrations. As Michal McMahon has shown, one came in the form of NASA's attempt to reshape the space agency's university program, a reshaping that sought to merge organizational and technological systems so as to achieve, in the words of an M.I.T. engineer, "inventions on schedule."[17] For NASA administrator James Webb, the goal was multidisciplinary research, to be brought about by gathering different disciplines to work in parallel within a center so as to stimulate cross-fertilization. The research was also to be interdisciplinary. It would involve researchers from different disciplines working together toward a common goal. "Webb," McMahon argued, "also wanted to use NASA to stimulate the universities to more actively transfer their knowledge to industry and to local governments working with community and social problems. This was an aspect of NASA's fervent desire to see more technological spin-offs from the space program."[18] But Webb and NASA ended up disappointed. By the standards set out in agreements between NASA and the universities, the program was a failure. It was axed by the Bureau of the Budget in 1970.

Justifying Big Science

During the rest of the 1960s, the 1970s, and the 1980s, in all administrations, there were other moves by the federal government to stimulate technological innovation. But of central concern for this chapter is that at roughly the same time as the national policy on technology and innovation shifted in the early 1960s, there was also a shift in the way advocates talked about Big Science projects.

In the early 1960s physical scientists usually had not felt driven to make direct claims to Congress about the technological spin-offs of Big Science research. Arguing for increased funding for the multi-hundred-million-dollar Stanford Linear Accelerator in 1964, its director stated that: "I am not of the school who tries to defend this kind of work through its byproducts. I believe if you want the byproduct, you should develop the byproduct. I think you would do it more economically and do it more effectively. If you want to push high powered radio tubes, then the best way to do so is to push high powered radio tubes and not to build accelerators which require high powered radio tubes."[19]

Big science for the sake of Big Science was hardly enough to sell really large-scale scientific projects in the late 1960s or during the 1970s. In the mid-1970s, for example, the scientific promise of the Space Telescope was simply not sufficient to win federal funding. While NASA was ostensibly selling in its public testimonies a scientific instrument of potentially prodigious power, Congress and the executive branch were buying much more, and the telescope advocates (among NASA, astronomers, and industry) had shaped the arguments Congress was buying.[20]

In seeking to justify the Telescope in 1975, for instance, NASA administrator James Fletcher told a congressional hearing that

> . . . the benefits of astronomy are generally longer term than some of the others we talked about. On the other hand, they are far-reaching in their impact. The benefit from Galileo's experiments was literally the industrial revolution. How can you put a figure on that? . . . There could be brand new energy sources downstream, just as nuclear energy came out of Einstein's investigations. By the way, that was astronomy too. The whole idea of relativity came out of astronomy."

When his congressional questioners pressed him to quantify the possible benefits, Fletcher responded that "Even though you try to put probabilities on realizing benefits, even if it is only 5 to 10 per cent, we are not talking about billions or trillions of dollars, we are talking about the salvation of the world."[21]

A Lockheed Missiles and Space Company document from 1975 that was used by advocates to sell the Space Telescope argued:

> Important as the direct benefits of the [Space Telescope's] investigations are apt to be, the program will also provide several more immediate but less apparent economic benefits. Many economists agree that advances in technology constitute a prime source of economic growth and increased productivity . . . It is also generally recognized that today this nation's ability to maintain a favorable balance of trade depends to a significant degree upon the pace of our technological developments. Today's science is tomorrow's technology, and advanced technology may well be the only unique product the U.S. has to export. The National Science Foundation has pointed out that high-technology products represent the only category of exports in recent years that have maintained a favorable trade balance.
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> The technological demands of a program such as [Space Telescope] will thus contribute to economic growth by providing a basis for increasing productivity and the maintenance of trade balances.[22]

If we move forward to the 1980s, the arrival of Ronald Reagan in the White House caused some alarm among advocates of federally supported basic research. Milton Friedman, for example, proposed major cuts in the National Science Foundation budget as a step toward the Foundation's abolition.[23] He was also supposed to have the ear of the incoming administration. But Reagan's rhetoric about the evils of big government did not mesh with the actions of his administration in the field of science policy. A more reliable guide to the administration's science policy would turn out to be a Heritage Institute study that stressed how central basic scientific research was to the nation's future.[24] As David Dickson has pointed out, this study was delivered to the incoming Reagan administration shortly after the 1980 election. It provided economic and cultural reasons to support science, and argued that "in a study filled with accounts of federal program failures it is refreshing to find an area filled with spectacular success—space and general science."[25]

In the last year of the Reagan administration the explicit linking of science and competitiveness, most strikingly Big Science and competitiveness, had become national policy. "The administration," Smith notes, "having backed off from its earlier plans for a more selective pattern of research support, now embraced scientific advance as the answer to the lagging productivity rate and the nation's problems of economic competitiveness. It invoked the unexpected synergies of research, along with the need to have patience and to avoid excessive 'targeting' so that long term benefits and spillover effects from research could be realized."[26] We thus see again the great chain of being argument, with Big Science portrayed as Big Business by another route. (Of course, there are many similarities between the two: scale, organizational complexity, costs, and technologies.) But at the same time, government-funded Big Science had become a very powerful symbol of national technical prowess, a point that I think helps to explain the outpouring of anger and confusion over the Space Telescope's flawed mirror discovered shortly after it was launched into space in 1990.

In recent years, then, the economic arguments deployed to justify Big Science projects have intensified. But as Michael Reagan and others have long pointed out, the kind of arguments used to link basic science and technology are similar to arguments made in classic economics. For classic economists, there was a hidden hand at work that translated the pursuit of individual self-interest into the pursuit of the general good. The hidden hand was identified with the mechanism of the marketplace. The Big Science/Competitiveness arguments have followed the same sort of structure. If scientists remain free to pursue their calling as they see fit, to satisfy their intellectual curiosity about nature, their efforts would inevitably—and without need for conscious intent on their part—contribute to the general good. Whereas classic economists had pointed to the marketplace as the hidden hand, the scientists and their advocates point to no such mechanism.[27] The impression given is that

> if one scatters a handful of basic research findings out among several industries and an assortment of engineers, and adds to that some open ended funding, one can guarantee technological success. On the contrary, there are a myriad of other issues and influences that can float or sink the technological boat. To mention just a few we know that tax policy, patent policy, availability of venture capital, antitrust laws, technological literacy in the workforce, industrial productivity, and innovation, are all factors of significant influence.[28]

Rather than attempt to break down the "Big Science equals increased competitiveness" arguments further, let me just focus on one version of this, that increasing national competitiveness arises from the novel technologies constructed to make the Big Science possible. A crucial point here is that Big Science projects cost so much that their advocates have generally been driven to be conservative in their choices of technology. One of the standard arguments made in favor of Big Science projects is in fact that they will rely on proven technology. In effect, existing technology has to be deployed to sell the project to the White House and Congress in the first place.

Hence the emphasis in building the technologies for Big Science has been on engineering ingenuity in devising new arrangements for existing technologies, not on making radical innovations. This is certainly not to say that such problems are straightforward, but it was not, for example, the experts in superconducting magnets at the national accelerator labs who made the recent breakthroughs in high-temperature superconductors.[29] The Hubble Space Telescope is also a combination of very well-established technologies.

One exception to this rule are the small electronic devices for detecting light known as charge-coupled devices (CCDs) carried in one of the Telescope's scientific instruments. But the development of CCDs for astronomy has been piggybacked onto commercial and military needs, not the other way around. The story of the CCDs is a very interesting one, but here I will say only that the concept that underlies them and its practical demonstration were achieved at Bell Labs in 1969. Three main U.S. companies developed the capacity to manufacture the CCDs: Texas Instruments, RCA, and Fairchild. The early development was driven by (1) the military and (2) the companies themselves, since they were interested in the potential of CCDs, in particular, for the home market. By the early 1980s, the only CCDs being manufactured in the United States were on a small scale for specialist scientific markets, while the manufacture of chips for commercial use had become dominated by Japan.[30]

Conclusion

In 1985, George Wise argued that the refutation of the assembly line model stands as a major contribution of historians to the discussion of the relation between science and technology in modern America. He nevertheless conceded that the evidence of the thinking of policymakers on the model was ambiguous. I think it is clearer now. For historians the message is not encouraging. In the realm of Big Science, the assembly line model, while it does not have complete sway, has in fact prospered on Capitol Hill and at the White House. In the face of such claims by advocates of Big Science, the arguments advanced by historians have often failed to be heard or have been brushed aside.

American policymakers have thus chosen to pin so much faith on huge government-sponsored projects; but none of the recently established projects for Big Science facilities seem to have much to do with industrial innovation or productivity, whatever the advocates might insist.[31] To analyze this situation, a French observer of the American scene, Jean-Claude Derian, has made use of the simile of technology as a mirage. "To Derian the mirage is something promising that becomes increasingly inaccessible—the brass ring that always remains just out of reach. But Americans have grasped that ring and flung it around the moon. We built the industries that set the target for others to challenge."[32] The American problem, long-time observer and analyst of American science and technology, Lewis Branscomb, has suggested, is not that the technology remains out of reach: "The problem is that the government's technology strategies and the management of the program have lacked precision, integrity, and discipline."[33] Justifying Big Science on the basis of the assembly line model of technology is, at best, one part of that lack of precision, and, at worst, integrity.

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Notes

1. In what follows, I shall also restrict my comments to Big Science associated with the physical sciences; for example, with the burgeoning of biotechnology industries, the situation for the biological sciences is different.
2. Office of Technology Assessment, *Mapping our Genes. The Genome Projects: How Big, How Fast* (Washington, D.C.: U.S. Government Printing Office, 1988), p. 125.
3. See Robert W. Smith, "The biggest kind of big science: astronomers and the Space Telescope," in *Big Science*, P. Galison and B. Hevly, eds., (Palo Alto, Calif.: Stanford University Press, 1992), 184–211.
4. See Jorge Niosi, Introduction, pp. xv–xix, and François Chesnais, "Technological competitiveness considered as a form of structural competitiveness," pp. 142–176, in *Technology and National Competitiveness, Oligopoly, Technological Innovation, and International Competition*, J. Niosi, ed., (Montreal and Kingston: 1991).
5. See Niosi, *Technology and National Competitiveness*, *ibid.*, p. xvii. Gille's concept of technical system seems similar in certain respects to Thomas Hughes's ideas of heterogeneous engineering: see, for example, Thomas P. Hughes, "The seamless web: technology, science, etcetera, etcetera," *Soc. Studies Sci.*, Vol. 16, 1986, pp. 281–292; also, ———, 1983, *Networks of Power: Electrification in Western Society, 1880–1930* (Baltimore, Md.: The Johns Hopkins University Press, 1983).
6. This point is made by Lewis Branscomb in his Foreward to Jean-Claude Derian's *America's Struggle for Leadership in Technology* (Cambridge, Mass.: 1990), pp. vii–x, vii.
7. *Washington Post*, "Supercosts of the supercollider," July 10, 1989, p. A10.
8. *Los Angeles Times*, "Atom smasher proposal weds science and politics," December 6, 1987, p. 10.
9. George Wise, "Science and technology," *Osiris*, Vol. 1, 1985, pp. 229–246, 236.
10. Vannevar Bush, for example, exploited this argument in his famous *Science, The Endless Frontier: A Report to the President* (Washington, D.C.: U. S. Government Printing Office, 1945).
11. Ernest Braun and Stuart MacDonald, *Revolution in Miniature* (Cambridge: Cambridge University Press, 1978), p. 1.
12. John R. Steelman, *Science and Public Policy: A Report to the President, Volume 1: A Program for the Nation* (Washington, D.C.: U. S. Government Printing Office, 1947).
13. Bruce L. R. Smith, *American Science Policy Since World War II* (Washington, D.C.: Brookings Institution, 1990), p. 85.
14. Harvey Brooks, "What's the national agenda for science and how did it come about?" *Amer. Sci.*, Vol. 75, 1987, p. 512.

15. Smith, *American Science Policy,* op. cit., p. 87.
16. Smith, *American Science Policy,* ibid., pp. 87–88.
17. Quoted in A. Michal McMahon, "Shaping a 'space-oriented complex': NASA and the universities in the 1960s," paper presented to the "'Science, Technology, and the Military" workshop at The Johns Hopkins University, Baltimore, Md., 1986, p. 4.
18. McMahon, "Shaping a 'space-oriented complex,' " ibid., p. 16.
19. House Committee, "Testimony of W. Panofsky on the Stanford Accelerator Power Supply: Hearing Before the Joint Committee," 88th Congress, 2nd session, January 29, 1964, pp. 24–25.
20. Robert W. Smith (with contributions by Paul Hanle, Robert Kargon, and Joseph N. Tatarewicz), *The Space Telescope: A Study of NASA, Science, Technology, and Politics,* Chaps. 4 and 5, New York: Cambridge University Press, 1989).
21. House Committee on Appropriations, "Department of Housing and Urban Development-Independent Agencies Appropriations for 1976: Hearings Before the Subcommittee on HUD-Independent Agencies, pt. 2, NASA," 94th Congress, 1st session, March 4, 1975, p. 427.
22. Lockheed document, "Potential benefits of the Large Space Telescope," January 27, 1975, copy in Space Telescope History Project Files, Smithsonian Institution, Washington, D.C.
23. Milton Friedman, "An open letter on grants," *Newsweek,* May 18, 1981, p. 99.
24. This was pointed out in Smith, *American Science Policy,* op. cit., pp. 109–110.
25. Quoted in David Dickson, *The New Politics of Science* (New York: Pantheon, 1984), p. 39.
26. Smith, *American Science Policy,* op cit., p. 157.
27. Michael Reagan, *Science and the Federal Patron* (New York: Oxford University Press, 1969), pp. 40–41.
28. Chairman's Report to the Committee on Science and Technology, House of Representatives, "American science and policy issues," 99th Congress, 2nd session, December 1986, p. 120.
29. J. L. Heilbron and D. J. Kevles, "Mapping and sequencing the human genome: Considerations from the history of particle accelerators," in *Mapping our Genes. Federal Genome Projects. How Vast, How Fast,* Vol. 1 (Washington, D.C.: U. S. Government Printing Office, 1988), pp. 160–179.
30. On the CCDs, see Robert W. Smith and Joseph N. Tatarewicz, "Counting on invention: Devices, telescopes, and black boxes," *Osiris,* in press.
31. Branscomb, *America's Struggle,* op. cit., p. vii.
32. Branscomb, *America's Struggle,* op. cit., p. viii.
33. Ibid.