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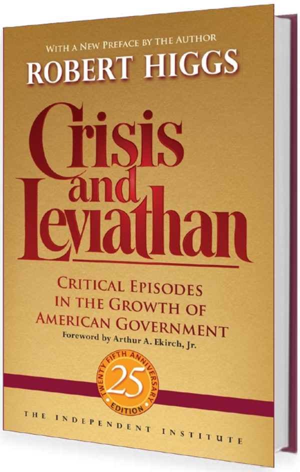

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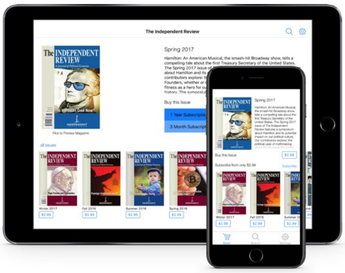

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Government and Science: A Dangerous Liaison?

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WILLIAM N. BUTOS AND THOMAS J. MCQUADE

With the rise of the modern state, science has become increasingly subject to government intervention in its funding and direction. This tendency's underlying driving force has been the growth of government itself. The governmental impetus to ensure politically determined adequate levels of scientific research and development (R&D) and to manage such efforts took hold in the twentieth century principally as a consequence of nationalistic hostilities or perceived threats of external aggression. This rationale was eventually augmented by more broadly based social agendas and by the "market failure" claim that academic economists advanced in the late 1950s (and since) with respect to the production of R&D, especially so-called basic research (see, for example, Nelson 1959; Griliches 1960; Arrow 1962). Since 1949, as shown in figure 1, the extent of government engagement in science has trended upward significantly, and the prevalent thinking of our times is that only fiscal constraints limit the magnitude of government funding of science.

There are serious reasons, however, for thinking that the liaison between government and science carries with it unrecognized dangers for the functioning and integrity of science as a reliable generator of knowledge. It is not so much that government seeks to exert a blatant and crude control over the content and direction of scientific inquiry—although such heavy-handed intrusion has precedents, most notably in the

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William N. Butos is a professor of economics at Trinity College, Hartford; **Thomas J. McQuade** is a visiting scholar in the Department of Economics at New York University.

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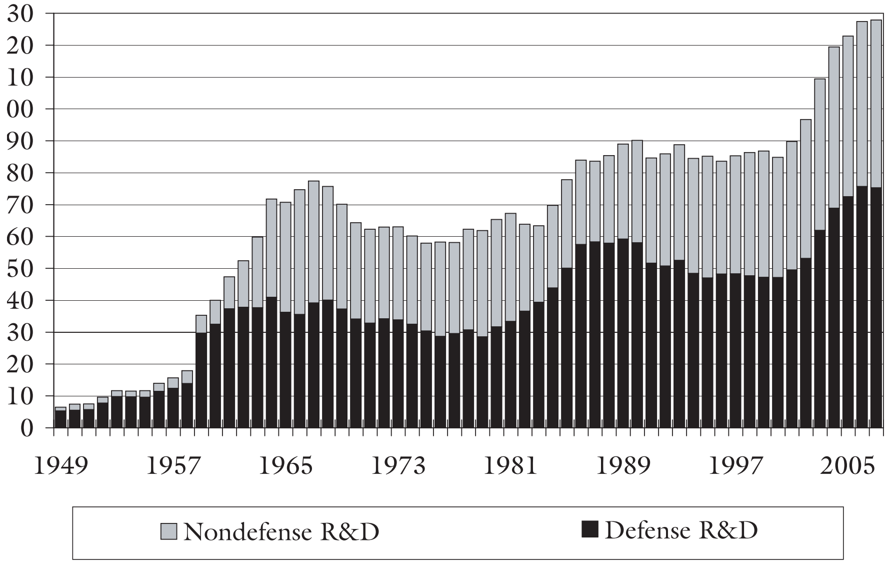
Figure 1
Federal Spending on Defense and Nondefense R&D, 1949–2007
(billions of 2001 dollars)



Note: Fiscal year 2007 is president's request.

Source: American Association for the Advancement of Science 2006a. Based on Office of Management and Budget in *Budget of the United States Government FY 2007.*

USSR—but that the structure and conduct of seemingly benign and generous government funding of science has side effects that generate instabilities in scientific activity in the short run and corrode the structure and adaptability of the system of science itself in the long run.

In this article, we briefly survey the relationship between government and science, concentrating on the situation in the United States in the twentieth century. We discuss in some detail the theoretical rationale for government funding, showing that it is open to serious question: its model of market failure in science is highly suspect, and its implications for the remedial effects of intervention do not stand up to even casual empirical scrutiny. Calling attention to the nakedness of the standard economic rationale, however, does not touch the actual political rationales. Following other commentators—Greenberg (2001), in particular—we direct attention to the interaction between these rationales and scientists' understandably strong desire to have their work well funded. Although we find Greenberg's and others' detailed descriptions of unease within science to be compelling, we think they suffer from a lack of any clear theoretical model of science as a social system. Therefore, to point the way toward a more comprehensive treatment, we devote considerable attention to an exposition of the various ways in which government funding interacts with scientists and the system of scientific activity to produce the unanticipated effects that concern us.

Historical Background

The U.S. government has funded isolated scientific research projects (broadly conceived) since the early days of the republic, as evidenced, for example, by the War Department's support of the Lewis and Clark Expedition and the congressional appropriation to support Samuel Morse's electric telegraph. The Civil War accelerated and broadened a federal presence in science, including the use of scientific advisors for wartime purposes and the congressional establishment of the National Academy of Science (NAS) in 1863. The federal government established the Department of Agriculture and the land-grant system of colleges, both of which provided institutional bases for government-funded scientific research that have persisted to this day. The Pure Food and Drug Act of 1906 established a permanent regulatory demand for scientific expertise. With the outbreak of World War I, the Navy Department constituted a naval consulting board (headed by Thomas Edison) to seek out applications of technologies for military purposes; it would become the Naval Research Laboratory after the war. President Woodrow Wilson created the National Research Council (NRC) as an offshoot of the NAS to study the government's scientific needs. The NRC coordinated wartime projects in optics and gas warfare that involved the military, private contractors, and government-sponsored university R&D. At the end of the war, this government-industry-university establishment was largely dismantled, and although the NRC was given permanent status, its activities during the 1920s greatly diminished owing to a lack of funding (see Dupré and Lakoff 1962; Rahm, Kirkland, and Bozeman 2000, chap. 2).

Although a government presence in scientific and technological R&D was well established by the beginning of World War I, it was not based on a principled, coherent, or explicit "national science policy." Instead, government support for science served largely transitory wartime exigencies. But this situation would change under Franklin D. Roosevelt's administration with the continuation of the Depression and the approach of war. In 1933, Roosevelt set up the Presidential Science Advisory Board and the National Planning Board (NPB) to enlist scientific expertise for solutions to the Depression. In 1934, the National Resources Board (NRB) replaced the NPB and subsumed within its jurisdiction the Science Advisory Board. As Feldman, Link, and Siegel point out, "after all the organizational issues were settled, the federal government recognized . . . that it had and would continue to have an important coordinating role to play in science and technology planning toward a national goal of economic well-being" (2002, 13).[1]

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[1] The idea that science should serve social and political objectives, as opposed to seeking "scientific truth," was not confined to America. Indeed, such enthusiasms were especially pronounced in England during the 1930s. Fueled by beliefs in the presumed success of Soviet central planning, the British government came under increasing pressure to organize scientific institutions so as to establish central planning for science. This movement was countered, almost single-handedly, by John Baker, Michael Polanyi, and their Society of Freedom in Science. This episode is analyzed in detail in McGucken 1984.

Of special note was the NRB's publication of a 1938 report entitled *Research—A National Treasure,* a comprehensive survey of government, industry, and university scientific activity that would provide the rationale and justification for a governmental science policy. The report argued that the government

1. is constitutionally obligated to support science and technology related to defense, scientific standards of weights and measures, and certain regulatory functions;
2. is more effective than the private sector in carrying out research, especially when private costs of research are high relative to its practical or social value; and
3. can stimulate industry research that is expensive and has unpredictable or delayed financial payoffs. (see Feldman, Link, and Siegel 2002, 13–14)

Once war broke out again, the government moved to harness scientific resources for military purposes. Of the 92,000 working scientists prior to the war, about 19,400 were employed in the government, and more than 72,000 were employed, in roughly equal numbers, at universities and at the more than 2,200 industrial laboratories (Feldman, Link, and Siegel 2002, 14). In 1940, Roosevelt established the National Defense Research Committee, replaced in 1941 by the Office of Scientific Research and Development (OSRD), to organize scientific and technological resources for the war effort. Under the chairmanship of Vannevar Bush, the former president of the Carnegie Institution in Washington and a one-time vice president of MIT, the OSRD did not conduct research, but it did establish contractual relations—a protocontractual framework—governing collaboration between government funding agencies and university and industry entities that undertook and administered sanctioned research.[2]

As World War II drew to a close, no concerted effort was made to dismantle the government's wartime involvement in science, in contrast to the post-World War I experience. Instead, Roosevelt asked Bush to prepare a report analyzing how the OSRD's role could be played in *peacetime* collaboration of government and the scientific community for achieving "improvement of the national health, the creation of enterprises bringing new jobs, and the betterment of the national standard of living."[3] Bush's report, published in 1945 as *Science—the Endless Frontier,* is perhaps the decisive document charting the institutional framework for science in the latter part of the twentieth century and into the twenty-first. The report claimed that government support of science is essential for medical advances, national security, economic welfare, and full employment. Bush argued that attaining these goals required that the "Federal Government should accept new responsibilities for promoting the creation of new scientific knowledge and the development of scientific talent in our youth" (25). This "national policy for scientific research and education" (28) was to be financed by

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[2] The University of California's Los Alamos Laboratory in New Mexico is an example of the OSRD's efforts. The laboratories built for the Manhattan Project came under the aegis of the OSRD and would later begin the U.S. national laboratory system.

[3] Letter from Roosevelt to Bush, November 17, 1944, quoted in Feldman, Link, and Siegel 2002, 15.

government funds, making payments to industry and subsidizing research as well as undergraduate and graduate student scholarships in universities. In addition to recommending expanded support for research and applied work conducted by government laboratories, the report highlighted the special role that colleges and universities should play in basic research.[4] The institutionalization of the federal government's reconfigured role was to be attained by the creation of the National Science Foundation (NSF), whose purpose was to "develop and promote" federal science policy and to implement policies aimed at supporting "basic research in non-profit organizations" (28). The report also charged the NSF with responsibility for developing scientific talent and for supporting long-range research with military applications.

Bush's central claim was that material progress depends on new scientific knowledge and that such knowledge, in turn, depends on what he called "basic research": research performed without thought of practical ends, as he defined it.[5] Implicit in this claim was the assumption that the federal government must provide the dominant guiding, coordinating, and financing role for the growth of scientific knowledge. He rested this assumption on a constitutional claim that the "[f]ederal government, by virtue of its charge to provide for the common defense and general welfare, has the responsibility of encouraging and aiding scientific progress" (1945, 68). The connection between national defense and military scientific and technological progress was not a new justification for an expanded role for government. Justifying this expansive role with reference to "public health, higher standards of living, conservation of national resources, new manufacturing which creates new jobs and investment opportunities, in short, the prosperity, well-being and progress of the American nation" reflected a vision that was reminiscent of, but surely more politically timely than the 1938 report *Research—A National Treasure*. Although the claim that marshaling the amount of research money necessary to satisfy these objectives requires substantial federal support appears throughout the 1945 report, no detailed analysis was provided to support it.[6]

Bush's report received crucial support with the timely publication in 1947 of *Science and Public Policy: A Program for the Nation,* by the President's Scientific

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[4] Of the fifty individuals who served on committees that reported to Bush, a majority listed academic affiliations (generally at the higher administrative levels); the next largest group comprised personnel from government agencies. The so-called Medical Committee consisted entirely of nine university-affiliated physicians.

[5] See Feldman, Link, and Siegel 2002, 16. Bush's claim that basic research necessarily precedes applied R&D and its eventual effects on material progress is often referred to as the "linear model," a paradigm that dominated policymakers' and academic researchers' views for decades, as we discuss later in more detail.

[6] The Bush report's argument for government funding of science does not rest on claims about market failure, but on a vague sense that "more scientific knowledge is desirable." The report in appendix 3 by the Committee on Science and Public Welfare, the one committee most closely associated with economics, provides data on scientific research expenditures by industry, colleges and universities, and government. However, only two economists, Rupert Maclaurin of MIT and Harold Moulton of the Brookings Institute, sat on this committee, and neither of them ever advanced market-failure arguments for science in their own academic work. Moulton, who came into prominence in the 1920s, was a leading authority on money, banking, and business cycles. Maclaurin did write on R&D issues; see, for example, his *Research and Innovation in the Radio Industry* (1949).

Research Board under the direction of John Steelman, an assistant to the president. The Steelman report argued that the government should allocate 1 percent of gross domestic product (GDP) to R&D,[7] while reaffirming the centrality of basic research for economic prosperity and growth, the belief that the private sector cannot reliably sustain such research, and the claim that R&D should be conducted principally by universities and industry with government funding.[8] The Steelman report also called for creation of a national science foundation to dispense government research funds. Congress did create the proposed agency in 1950 under the National Science Foundation Act. Since the 1950s, the essential contours of government and science interaction in the United States have taken the forms proposed in the Bush and Steelman reports.[9] The principal divergence has been in the magnitude of the funds the government has dispensed.

Thus, the long-standing but largely piecemeal incursion of government into science since the eighteenth century gave way in the twentieth century to the creation of formal government institutions and associated funding mechanisms during World War I and especially during World War II. Most of this activity was war related. In the aftermath of World War II, however, initiatives were taken to promote government involvement in science on the grounds of economic development as well as national defense; the Bush and Steelman reports were pivotal in molding government science policy after World War II. Creation of the NSF in 1950 actually brought to an end a controversy over science policy within the government that had raged for several years among those such as Bush and Steelman who argued for an indirect government role in science (by means of government financing of university and industry science via a collection of mission-oriented agencies) and those who argued for a direct role (by means of governmental coordination and management of science). The latter position, most famously maintained by Democratic senator Harley Kilgore of West Virginia, envisioned a centralized government agency that would "*direct* and consciously *plan* the advance of scientific research and technology" (Kleinman 1995, 6, emphasis in original). For about five years, beginning in 1942, Kilgore introduced several legislative proposals for the creation of a centralized government science agency controlled and administered by representatives of a wide range of social interests, including both scientists and nonscientists (Kleinman 1995, chap. 5).

The eventual defeat of Kilgore and his New Deal associates by Vannevar Bush, both in legislation and in the widespread acceptance of Bush's *Science—the Endless Frontier* (1945), is traditionally viewed as a victory for a decentralized approach (Kleinman 1995; Feldman, Link, and Siegel 2002). But if this outcome can be called a victory, it was certainly a shallow one. In the aftermath of World War II, government involvement in science followed the outlines of the Bush approach, but the scale of

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[7] *The Endless Frontier* urged that federal funding attain an annual level of $122 million.

[8] President's Scientific Research Board 1947, 1:3–7. The President's Scientific Research Board was composed entirely of Cabinet secretaries and other government officials, including Vannevar Bush.

[9] See Feldman, Link, and Siegel 2002, 19, for an overview.

government funding swept away historical precedents and established funding norms that have persisted with little change into the present.

Science Funding since World War II

The precedent for increased government funding of science, established during the war years with an emphasis on military R&D, and the subsequent legitimizing of a broader justification for government in science set the stage for substantial increases in government funding after 1949 (see figure 1).[10] In 1949, total federal R&D spending (measured in 2001 dollars) was approximately $5 billion; by 1964, it had increased to approximately $65 billion--a thirteenfold increase, bolstered by the political considerations that attended the Cold War. The proportion of defense to nondefense R&D spending was approximately 5 to 1 in 1949 but decreased steadily to approximately 1.4 to 1 by 1963, a ratio that is typical for much of the period since then. From 1964 to 1969, nondefense spending (of which spending for the National Aeronautics and Space Administration [NASA] was a large component) increased dramatically, and total R&D spending hovered in the $60 billion to $70 billion range. From 1970 to 1983, some retrenchment occurred, with federal spending hovering near the $55 billion mark, but thereafter defense spending increased sharply (whereas the nondefense component shrank modestly), so that total R&D spending edged toward $75 billion. Declines in defense spending beginning in 1991 and continuing until 2001 were more than offset by nondefense increases that kept total federal R&D spending around the $75 billion mark during the decade.

Figure 2, which contains more recent data for total federal R&D expenditures on defense and nondefense, illustrates more clearly the relative sizes of these two R&D components. Also, in the years since 2002, R&D outlays for defense have increased sharply. For fiscal year 2006, the president requested R&D funding of approximately $130 billion.

We also note that since the mid-1960s, the share of federal R&D expenditures in total budget outlays has declined and given way to a more or less stable ratio.As shown in figure 3, this ratio has averaged approximately 5 percent of the federal budget since the early 1970s. Of course, given the rise in the overall federal budget during this period, the declining and now stable ratio of federal R&D to total budget outlays still represents significant increases in federal funding for R&D in absolute (and constant dollar) terms.

The empirical data presented in our figures suggest that the explosion of government funding of science following World War II is significant and without precedent.

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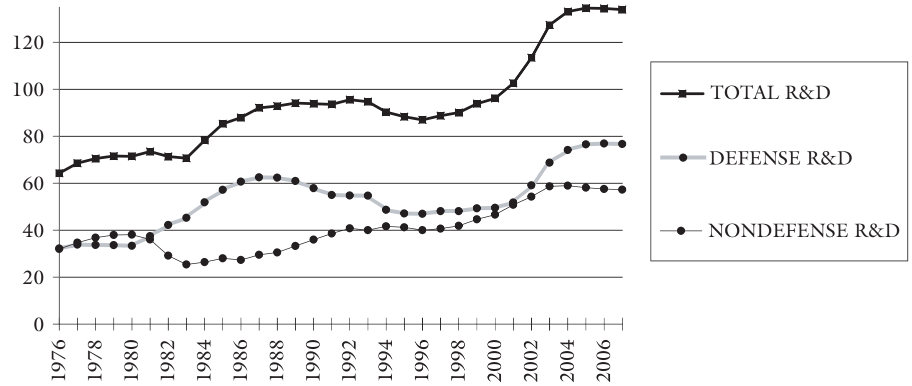
[10] As defined by the NSF, research is "systematic study directed toward fuller scientific knowledge or understanding of the subject studied," and it comprises *basic research* ("systematic study directed toward fuller knowledge or understanding of the fundamental aspects of phenomena and of observable facts without specific applications toward processes or products in mind") and *applied research* ("systematic study to gain knowledge or understanding necessary to determine the means by which a recognized and specific need may be met"). *Development* is "systematic application of knowledge or understanding, directed toward the production of useful materials, devices, and systems or methods, including design, development, and improvement of prototypes and new processes to meet specific requirements" (2005a, 1).

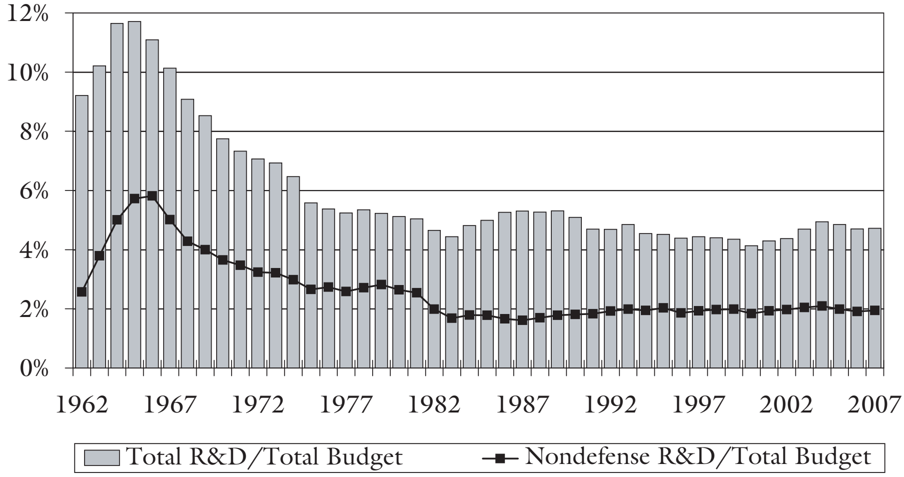
Figure 2
Trends in Federal R&D Expenditures, 1976–2006
(billions of 2005 dollars)



Note: Fiscal year 2006 data are President's request.

Source: American Association for the Advancement of Science 2006c. Based on *ASSA Reports VIII–XXX*.

Figure 3
Federal R&D Expenditures as a Percentage of
Federal Budget Outlays, 1962–2005 (Preliminary)



Note: Fiscal year 2005 data are budget proposals.

Source: American Association for the Advancement of Science 2005. Based on *Budget of the U.S. Fiscal Year 2005. Historical Table.*

This ratcheting in the magnitude of government funding reflects the effects of the interplay between the machinations of the political process and justifications stemming from threats to national security, the desire to attain top-shelf world ranking in (nondefense) basic research, and, more recently, post-9/11 antiterrorist R&D funding.[11] But whatever the perceived immediate need (real and otherwise) or political pressure used to justify government funding of science, a set of arguments exists behind the screen that claims to establish a general theoretical justification for such funding. We turn next to a critical examination of these arguments.

Rationales for Government Funding

The principal theoretical justification for government involvement in funding and directing the activities of scientists and the dissemination of scientific knowledge rests on a "market failure" argument, which claims that the characteristics of scientific knowledge are such that it will be produced in suboptimal quantities without intervention.[12] Nelson (1959) and Arrow (1962) offer the classic statements of this argument; Dasgupta and David (1994) have restated and augmented it more recently.[13] Taking the classic and the modern treatments in turn, we show their theoretical basis to be surprisingly weak and their empirical support to be conspicuously lacking. Our major criticism, however, is that these authors, in concentrating on the "simple economics" (and on sociology, in Dasgupta and David's case) of scientific research, ignore the political economy of government funding arrangements and their effects on the system that generates scientific knowledge.

Nelson suggests that in a regime of nonintervention, underinvestment in basic research would occur of necessity, largely because of "the classic external-economy problem" (1959, 306).[14] Firms other than the one conducting the research can benefit

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[11] Budget appropriations to combat terrorism have been one of the fastest-growing aspects of federal R&D funding. For example, from fiscal year 2002 to 2003, appropriations for counterterrorism activities by various agencies, including Defense, Health and Human Services, National Institutes of Health, Environmental Protection, and Justice increased from $1.2 billion to $2.9 billion (National Science Board 2004a, 4.28 and 4.29). Subsequent budgets (since the creation of the Department of Homeland Security in January 2003) have not separated counterterrorism R&D from other R&D programs.

[12] Of course, within the context of neoclassical economic analysis, "the observation of external effects, taken alone, cannot provide a basis for judgment concerning the desirability of some modification in an existing state of affairs. There is not a *prima facie* case for intervention in all cases where an externality is presumed to exist. The internal benefits from carrying out the activity, net of costs, may be greater than the external damage that is imposed on other parties" (Buchanan and Stubblebine 1962, 381).

[13] Many commentators on the economics of scientific research, in addition to Dasgupta and David (1994), are indebted to Nelson and Arrow for various aspects of their analysis. See, for example, Radnitzky 1986; Diamond 1988; Brock and Durlauf 1999; many of the papers republished in Mirowski and Sent 2002; and a series of papers summed up in Ziman 2002. We do not deal here with treatments of science that explicitly represent science as a type of market. The most thoughtful of these treatments is Walstad 2002; for an analysis and criticism of the analogy, see McQuade forthcoming.

[14] Nelson allows that "the profit motive may stimulate private industry to spend an amount on applied research reasonably close to the amount that is socially desirable" (1959, 305). His characterization of applied research, in contrast to basic research, is one of a matter of degree: research is more basic to the extent that "the degree of uncertainty about the results . . . increases, and the goals become less clearly defined and less closely tied to the solution of a specific practical problem or the creation of a practical object" (300).

from the results, but the generating firm's ability to internalize that value by patenting is severely limited.[15] Further, the inability to appropriate their results effectively leaves the firms with the option of keeping the results secret, but this practice is inefficient from a societal perspective, owing to the public-good nature of knowledge. As Nelson puts it, the "marginal social cost of using knowledge that already exists is zero" (306), so whereas free access to all knowledge generated is optimal from a societal point of view, such is not the case from the generating firm's point of view. To mandate a common pool for all basic research generated by private firms would reduce the incentive for knowledge production in the first place. Nelson concludes, then, that publicly funded, industry-independent research institutes and universities are the preferred organizations for conducting basic research because "were the field of basic research left exclusively to private firms operating independently of each other and selling in competitive markets, profit incentives would not draw so large a quantity of resources to basic research as is socially desirable" (Nelson 1959, 304). Moreover, because private firms (presumably operating at the point where expected marginal revenue is equal to marginal cost) do in fact conduct some basic research in the face of reduced incentives, this activity is an indication that the current funding of public research is less than optimal.

Arrow elaborates on Nelson's arguments, highlighting the inherent riskiness of research, the indivisibility of its product, and the lack of appropriability of the product's value as sources of inefficiency in a free-market environment that government intervention can ameliorate. The problem of risk is straightforward: "Since [invention] is a risky process, there is bound to be [on the part of risk-averse individuals] some discrimination against investment in inventive and research activities" (1962, 616). Arrangements for shifting the risk, including insurance, are incomplete or have optimality problems of their own. Therefore, as the solution to this problem, he posits "government or some other agency not governed by profit-and-loss criteria" and capable of risk neutrality (619). The problems of indivisibility and lack of appropriability are simply the public-goods problem discussed earlier, and Arrow, following Nelson, concludes that in "a free enterprise economy, inventive activity is supported by using the invention to create property rights; precisely to the extent that this is successful, there is an underutilization of the information" (615).

Setting aside for the moment the political economy of government intervention in science, the economics of the Nelson and Arrow analysis has three fundamental problems:

First, their underlying model of the processes of knowledge generation, appropriation, and utilization is institutionally inadequate. In fact, for the case of a private firm, no process is envisaged that differs in principle from that of making, selling, or

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[15] Nelson also suggests two other factors that reduce the incentive for private firms to pursue basic research: "the long lag that very often occurs between the initiation of a basic research project and the creation of something of marketable value" and "the very large variance of the profit probability distribution from a basic research project" (1959, 304).

using a commercially useful good. The good in question is simply problematic from the point of view of the profit-seeking firm because of uncertainty in production, difficulties in appropriation, and indivisibilities in consumption.[16] No account is taken of the more complex arrangements in which firms can and do hire scientists, encouraging them to conduct basic research and to publish the results freely, expecting that this activity will enable them to learn about and make use of published research appropriate to the firm's narrower production goals.[17] And no account is taken of the fact that scientific knowledge is in general not like a simple "recipe" or "blueprint" that can be put to immediate use.[18] To understand it, let alone to utilize it profitably, requires both entrepreneurial insight and a considerable investment in acquiring and maintaining the requisite background knowledge. In short, scientific knowledge has a tacit component that cannot be conveyed easily, which renders published scientific information, though necessary, insufficient for garnering free-rider profits.[19]

Kealey's analysis is particularly instructive here (1996, 225–30). It is based, first, on identifying two kinds of advantages associated with basic research and, second, on recognizing some pertinent institutional detail about firms, scientists, and R&D. Basic science, says Kealey, confers "first-mover advantages" on a company when it discovers something first. This kind of advantage may position the company farther along the learning curve in developing the discovery's commercial applications. At the same time, though, if companies derived only first-mover advantages from basic research (as Nelson and Arrow assume), such research would be unlikely to enjoy widespread commercial support because basic science is commercially unpredictable. "Second-mover advantages," in contrast, derive from a company's ability to generate commercial applications of *existing* basic research; these kinds of advantages are less risky and more profitable than basic research.[20] As Kealey observes, "first- and second-mover advantages are indissolubly

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[16] Even if these characterizations of knowledge are taken at face value, the presumed incentive effects do not necessarily follow. As Rosenberg argues, the "mere *existence*" of uncaptured benefits "is never an adequate explanation for the reluctance to perform basic research" (1990, 167, emphasis in original), provided the firm can capture sufficient benefits from its research. Even though the research may generate spillovers, it is not their magnitude that matters, but the return on investment the firm is likely to realize from derivative commercial applications.

[17] Rosenberg (1990) reports that firms fund basic research because it generates cross-fertilization of ideas, problem solving, and creativity among scientists and other company employees. Hicks (1995) observes that firms find it in their interest to hire freely publishing research scientists for a variety of reasons: such an employment practice provides access to research networks, keeps their scientists engaged and up-to-date, and presents an image in the academic and scientific community conducive to recruitment.

[18] On this point, see Pavitt 1987 and Rosenberg 1990.

[19] Dasgupta and David appear to disagree, saying that they "find no compelling grounds for associating the tacit knowledge of either technologists or scientists necessarily with skills that are specific rather than 'generic' in their applicability" (1994, 494). But simply to say that "the boundary between the codified information and tacit knowledge in a specific field of scientific research may be shifted endogenously by economic considerations" (495) does not do away with the disincentive of the cost of actually acquiring the skills, especially given that the particular skills needed may not be predictable in advance.

[20] Kealey (1996) reports on a 1992 study of Japanese pharmaceutical firms by Odagiri and Murakimi that found rates of return from basic research and "second-mover" research to be 19 percent and 33 percent, respectively.

linked, and one cannot be performed without the other. . . . [Thus,] second-mover advantages enforce a vast expenditure on basic science" (1996, 229).

Second, Nelson's and Arrow's analyses of what set of institutional arrangements for managing the activity of basic science would be more efficient than the autistic "market" arrangements they model commit what Demsetz calls "the nirvana fallacy" (1969, 1). A model of a supposedly realistic institutional arrangement is analyzed and found to be suboptimal relative to an idealized arrangement whose possible shortcomings are not analyzed. As Demsetz puts it,

> Arrow compares the workings of a capitalistic system with a Pareto norm that lends itself to static analysis of allocation but, nonetheless, that is poorly designed for analyzing dynamic problems of production. He finds the capitalistic system defective. The socialist ideal, however, resolves static allocation problems rather neatly. But this is only because all the dynamic problems of production are ignored. The comparison of a real capitalistic system with an ideal socialist system that ignores important problems is not a promising way to shed light on how to design institutional arrangements for the production and distribution of knowledge. (1969, 12)

On the matter of the riskiness of basic research, for example, it is quite invalid to assume that the risk-averse actors populating the "free-market arrangements" model would be replaced by risk-neutral actors in the "ideal arrangements" model. And questions of "underutilization" presume an ability to determine, under the ideal arrangements, what quantity and direction of research to pursue for maximum utilization—a dubious assumption at best.[21]

Third, Nelson and Arrow assume without analysis that the only adequate source of funding for basic research is the government.[22] The empirical record shows, however, that private sources consistently commit substantial sums to basic research as well as to R&D.[23] As shown in figure 4, basic research by firms accounts for approximately $8 billion to $10 billion per year. Other nonfederal sources of funding for basic research—which include nonprofit organizations, universities, and state governments—brought

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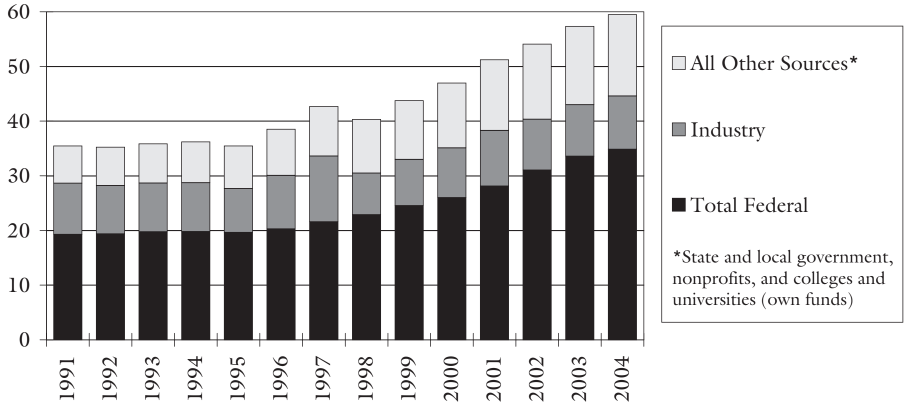
[21] These issues are discussed in detail in Demsetz 1969. Although we endorse Demsetz's criticisms of Arrow (1962), we have reservations about some of his suggested solutions. For example, we do not see that the creation of property rights in basic scientific results is a reasonable or viable arrangement. (We should be clear here that we *do* see the viability and desirability of the appropriation of services that enable the dissemination and use of basic scientific discoveries. For example, the base sequence of the human genetic code is a scientific discovery published openly and owned by nobody, but the database containing this code and allowing access to tools for gene search and identification is the property of its developer.) Also, see Walstad 2002, 25, for a sensible critique of treating research contributions as "intellectual property."

[22] No indication is given as to how one would actually determine the marginal social return for a research project in order to contrast this return with the (equally indeterminate) social opportunity costs of activities forgone owing to the government's extraction of the funds from the public.

[23] They do so because they expect the action to be profitable. Mansfield (1980) estimates an implicit rate of return of 27 percent on total R&D (1960–76) for chemical and petroleum firms. He finds a strong independent relationship between basic research and productivity; however, that finding may "reflect

Figure 4
U.S. Basic Research Expenditure, by Funding Source, 1991–2003
(billions of 2003 dollars)



Source: American Association for the Advancement of Science 2006d. Based on *NSF, National Patterns of R & D Resources: 2005b.*

the total to more than $20 billion in 2003, or approximately 40 percent of the total funding for basic research. For total R&D expenditures by source, the data reveal that industry has allocated increasingly significant resources toward R&D. As seen in table 1, total industry-funded R&D expenditure since 1980 has exceeded federal R&D expenditure and is now (according to data for 2003) nearly twice as great.

Whether the amounts of basic science and total R&D expenditures undertaken by the private sector are "optimal" survives only as a model-dependent question and lacks empirical content. Indeed, the standard neoclassical argument assesses optimality across only the quantity dimension. More is always better. Because the argument cannot rule out utterly perverse kinds of scientific research funding, it implicitly requires a second-order criterion for the allocation of research funds that must emanate from a political process.[24] Once account is taken of this political element,

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a tendency for basic research findings to be exploited more fully by industries and firms responsible for them" (871). He suggests that basic research may be a proxy for long-term applied R&D (866). Griliches finds that R&D, especially basic research, and the fraction of research financed privately (versus federally) contribute positively to productivity growth. According to his estimates, "raising the stock of R&R by 20 percent but shifting it all into the private component doubles the effect of such dollars" (1986, 149). Interestingly, he acknowledges that such results may be flawed because R&D often aims at creating new products as opposed to increasing productivity. He finds that firms tend to capture high returns from basic research, even if it is assumed that 50 percent of the positive effects of basic research are diffused throughout the industry. Working with data for the years from 1967 to 1977, Griliches (1987) also shows that dollar for dollar, industry-financed basic research contributed far more to economic growth than did government-financed basic research. Kealey claims that these findings support the notion that private companies "fund basic science comprehensively" and that this practice is "highly profitable" (1996, 225).

[24] For example, scientific tests of radiation exposure on U.S. servicemen and prison inmates during the 1950s.

Table 1
National Funds for R&D, by Source, 1970–2003 (millions of 2003 dollars)

	1970 Actual	1980 Actual	1990 Actual	2003 Prelim.	Percent Share of Total 1970	1980	1990	2003
Federal	57,801	58,909	79,831	85,279	57.0%	47.4%	40.5%	30.0%
Industry	40,307	60,784	107,821	179,615	39.8%	48.9%	54.7%	63.3%
Colleges and Univs.	999	1,808	4,130	7,944	1.0%	1.5%	2.1%	2.8%
State/Local	914	1,020	1,813	2,710	0.9%	0.8%	0.9%	1.0%
Nonprofits	1,323	1,712	3,355	8,247	1.3%	1.4%	1.7%	2.9%
TOTAL	101,341	124,232	196,949	283,795	100.0%	100.0%	100.0%	100.0%

Source: American Association for the Advancement of Science 2004b. Based on data from the Division of Science Resources Statistics, National Science Foundation.

the presumed "optimality" argument is underdetermined. In short, all that can actually be said is that the private sector, of its own choice, does undertake the funding of significant amounts of both basic research and R&D.

In the standard market-failure argument, no account is taken of the possibility, discussed by Martino (1992, chap. 27), that a side effect of government funding of science has been the driving out of funding contributions from private foundations and endowments, rich private donors, and the general public. No evidence is presented to support the assumption that these sources of funding would simply remain at their current levels were government funding to be significantly reduced or eliminated. In addition to the opportunities for reputational enhancement (individual or institutional) and even for immortality that funding of a selected institution, research project, or individual scientist might present, science has popular appeal as a societal "good" and is unlikely to be left seriously impoverished by a retreat of government intervention.

Dasgupta and David (1994) restate the Nelson-Arrow economics of science and augment it significantly by taking into account the particulars of the different institutional arrangements through which scientific and technical knowledge is generated. They distinguish sharply between "open science" (the research arrangements characteristic of universities and of nonprofit or government research institutes in which the reputation-based reward system works to hasten both discovery and its disclosure) and commercial R&D, or "technology," in which the reward system is oriented to material benefit and the desire for profit is not conducive to open disclosure. They do not advocate one of these arrangements over the other: although "it is evident from the contradictory norms on which they are based that there is a tension between these two modes of economic and social organization, so that they do not 'mix' easily, the two are not mutually exclusive ways to successfully organize the pursuit of scientific knowledge within the same society" (498). In fact, given that both modes are operative in modern society, the relevant policy problem is to "attend to maintaining a synergetic equilibrium between them" (498).

This is not to say that no "inefficiencies" exist in each of the two knowledge-production arrangements. Dasgupta and David point to problems in technological knowledge markets, including thinness (and therefore lack of efficient pricing),[25] leakage (owing to the inevitable disclosures that must be made in a sales situation), and underutilization on a societal basis (echoing Nelson and Arrow) (496–97). These problems can be offset in large part, but certainly not completely, by patenting, secrecy, and the incentive provided by the anticipation of monopoly profits.[26] Open science, they say, has problems of rivalry (which can weaken the incentive to prompt disclosure), resource allocation (in which the "all-or-nothing" aspect of the priority-based reward structure encourages the selection of research projects that are unduly risky or overly similar and leads "to the possible neglect of other areas in which the entry of even a few competitors might be socially beneficial"), and timing (the difficulty of achieving optimal sequencing of projects in a decentralized arrangement) (500–501, 505–10). These problems, they allege, can be dealt with, at least partially, by the diligence of public funding agencies.[27]

The main conclusion emphasized by Dasgupta and David is the policy point, noted earlier, that these two modes of knowledge generation, each adequate (if not perfectly optimal) in its own environment, need to be maintained "in dynamic balance" (510). Firms benefit from the results of open science (not necessarily immediately, but eventually) and from its training and certification of researchers, and this benefit redounds to society: "the important economic payoffs to society from basic research come in the form of higher rates of return on expenditures allocated to applied research" (510).[28] They assert that this "science-technology nexus" *must* be maintained by government funding and offer a stark warning of the consequences of

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[25] Also see Arrow 1971.

[26] The existence of monopoly profits would indicate an inefficiency, however, at least relative to a Pareto ideal.

[27] In this context, peer review is widely regarded as a vital mechanism for ensuring a rational allocation of public funding. But see Martino 1992, chapter 5, for a discussion of its strengths, limitations, and inherent problems. However, given that there is to be public funding, with its inevitable conflict between expert judgment and public accountability, then peer review seems as good a mechanism as any relative to the alternatives (bureaucratic selection, selection by political influence, and formulaic selection such as seniority—all of which have that conflict).

[28] Dasgupta and David do not make the mistake of subscribing to the simplistic and unidirectional "linear model" in which investments in basic science lead directly to economic growth via technological change. This model of economic development through science was recognized as defunct on scientific grounds in the 1960s, although it lives on for political purposes. Its proponents argue that without the appropriate amount of basic research, technological innovations and material progress will lag, and the government must provide the funding necessary to sustain an adequate amount of basic research and thus to promote economic growth. The basic error in the model (apart from the assumption of the necessity of government provision of funding) is the claim that new basic science drives technological change. Existing science and existing technology, however, have been found to cause technological change. For more discussion on this topic, see Kealey 1996, 204–5; Greenberg [1967] 1999, 29–30; Martin and Nightingale 2000; and Feldman, Link, and Siegel 2002, 17.

doing otherwise: "Under conditions approaching the state of 'universally privatized science' that such ideologues [that is, 'conservative' policy commentators] call for, an unbalanced research regime might continue to generate economic growth through the exploitation of the scientific and technological knowledge base, but sooner or later, economic progress almost certainly would lose the sustained character that has been taken by many scholars to distinguish ours from previous historical epochs" (515). They present no evidence for this claim, however.[29]

Although Dasgupta and David's introduction of real-world institutional considerations into the economics of science is a welcome advance, we find the following deficiencies in their argument for government involvement in the funding of science.

First, they add nothing to the basic Nelson-Arrow assertion, criticized previously, that private funding would turn out to be inadequate were government removed as a source of funding. In contrast to the scenario described in the passage just quoted, it is not credible that the advance of basic science, important in the long run to technological development, would slow to an extent that would have a marked effect on economic well-being. Our skepticism does not reflect a blind faith in the workings of the market—we have no truck with the pronouncements of policy pundits, conservative or otherwise—but rather an appraisal of the many possible motives, not limited to profit seeking, for supporting open science in the absence of government intervention and for maintaining the operation of the productive "science-technology nexus."[30]

Second, they assume that basic science performed in a private funding environment would not be published openly (at least not without a considerable delay), but rather would be conducted in secrecy to guard against exploitation by competitors. There is no reason for such secrecy to prevail with private nonprofit funding, however, and even for science funded internally by profit-seeking firms, secrecy is not necessarily the best strategy, as our previous discussion of "second-mover advantages" makes clear.

Third, their insistence on the importance of government funding to the continuing growth of basic science, together with the downstream importance of the application of earlier basic science for economic growth, suggests that the massive increase in government funding of science immediately after World War II would show up sooner or later as a discontinuity in the pattern of economic growth. Yet, more than fifty years later, no such discontinuity has occurred. No significant correlation can be seen between the amount of federal expenditure on basic science and the trend in GDP per capita, as documented by Kealey (1996, 162) for the nineteenth and twentieth centuries.

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29. David (1997), in a very critical review of Kealey 1996, maintains that private R&D funding is no substitute for public funding, and he disputes Kealey's finding that government funding crowds out private funding. Suffice it to say that the statistical evidence that can be gleaned in an environment of heavy government funding is inconclusive and probably subject to a variety of interpretations. Our appraisal of the institutional structures at play and the incentives they embody, however, leads us to suspect that Kealey is closer to the truth.

30. Such motives include, in addition to profit seeking, the usual motives of private donors (which range from a sense of civic duty to a desire for immortality by association) and the institutionalized motives of foundations and trusts.

Fourth, they do not extend their real-world institutional analysis to encompass the government funding mechanisms themselves. Although they allude to the possibility of commonalities with some areas of public economics (1994, 510), they do not consider the particular incentives characteristic of government funding agencies, such as those documented by Martino (1992), which manifest themselves in favoritism, scientific conservatism, and pork-barrel spending. In the absence of any serious institutional analysis in this area, one is left with a "public-interest" picture of government that, in the face of public-choice skepticism, requires for credibility specific attention to any mechanisms that might turn the normal self-interest of politicians and funding agency bureaucrats to the service of some concept of public interest.

Our conclusion is thus that the economic justification for government funding of science is (1) theoretically unconvincing because it ignores institutional arrangements within firms that negate the force of the "market failure" arguments and because it does not account for the institutional realities of political and bureaucratic funding agencies, and (2) empirically suspect because it ignores the substantial evidence of the robustness of the private provision of scientific knowledge and because it predicts that increased government funding above trend would (with an unspecified lag) result in increased economic growth above trend, a putative link for which no solid evidence exists.

Nevertheless, the extent of government engagement in science has trended upward for decades. This trend suggests that the forces driving the increase have more to do with a confluence of interest between politicians and scientists—a dynamic investigated in some detail by several scholars, including Martino (1992), Savage (1999), and Greenberg ([1967] 1999, 2001).[31]

An Analysis of Science Interventionism

The evolution of government policy with regard to science since World War II is best understood as a variant of an interventionist system rather than as a system of benign, decentralized support imagined by Vannevar Bush and others. Further, although the U.S. government's current role in science is not technically that of a central planner, many of the considerations that apply to centrally planned economic systems also apply in some degree to the ongoing arrangements between government and science in this country.[32]

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[31] Greenberg's (2001) work is especially enlightening. He describes in detail the history of the increasing entanglement of science and politics in the United States from World War II to the present: the enormous growth in government funding of the physical and biological sciences; the ways in which scientists and their universities have operated to claim and foster the increase of that largesse; the surprisingly unscientific, but politically effective propositions they have promoted to justify their right to public funding on a large scale; and the practical political reasons why legislators are likely to have the incentive to go along with the arrangement. He sees scientists as having succeeded beyond their wildest dreams in extracting public funds for their own use, but cautions that this activity has come at the expense of "the ethics of science." According to Greenberg, access to funding is surpassing reputation as a motivating force in science, a change that has led to an undermining of collegiality and, in some cases, honesty within science. As he sees the situation, the traditional standards of science have been corrupted by decades of misleading representations to the public and the government in pursuit of public money.

[32] See Ikeda 1997 for a similar argument in the context of government-market interactions.

In the absence of outside intervention, science is a decentralized system of social interaction that operates according to generally understood rules associated with the institutions of publication and citation (McQuade and Butos 2003). There is no controlling authority because power is distributed (not necessarily evenly, but still widely) across the population of participants. The institutional arrangements of science explicitly cater to all participants' self-interest. The process of interaction constrained by these arrangements results in observable side effects stabilized by negative feedback: the corpus of scientific knowledge and participating scientists' generally acknowledged reputations. This stabilization, however, does not preclude variation of the side effects in response to environmental changes, and these relatively stable side effects provide not only general and nondiscriminatory benefits even to nonparticipants, but also the incentive for a positive feedback effect on participation in the system.

Science in and of itself generates no revenue, so the expenses associated with scientific pursuits must be funded by other sources.[33] Because few scientists are independently wealthy, they are commonly employed as teachers in academic institutions, receiving both a salary for personal maintenance and some financial support for the operational expenses of their scientific activity. They may also receive support directly from private donors or corporations,[34] and they may be financed by grants of public funds. It is not surprising that these different funding sources should have different effects on the practice of science. Examination of such effects leads directly to a consideration of intervention in science, for it is through funding that organizations outside of science can most easily affect scientists' actions, introduce new incentives, exercise control, and alter the adaptive characteristics of the knowledge-generating system as a whole.

The three broad sources of outside funding (donors, businesses, and legislatures) have an obvious similarity: in each case, the funding, or its continuation, has strings attached. Donors may be motivated by civic duty or by a desire for the immortality of association with a fundamental advance or a large institution; businesses by the indirect profitability of such funding; and legislators by the benefits that the expenditure of the funds produces in their districts or by the enhancement to their reelection prospects associated with their promotion of a good and popular cause. The first two source types

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[33] We treat science as a distinguishable social process—the publication/citation regime—that clearly does not involve monetary exchange and hence revenue. We do not deny that, in practice, science is embedded in the market and depends on market-generated revenue for the maintenance of the people involved. Nor do we deny that aspects of scientific knowledge (or even aspects of the individual knowledge of a particular researcher) can be marketed (even patented) by organizations such as corporations and universities that employ scientists.

[34] People who work for corporations or government departments engaged in research that is not openly published are not participating in science as defined here. (Or, they may be doing so on a small scale, limited to the confines of their organization, if they circulate papers and cite the work of others within their local circle.) Such organizations, however, often do employ scientists and pay them a salary while allowing them to publish in the usual scientific outlets. We do not deny that a researcher who does not publish may be doing "science" in the sense of doing some of the things that one expects scientists to do—for example, experimenting, thinking, and formulating hypotheses—but in order to affect scientific knowledge, a contribution must be published in some form. Only published contributions can be assessed, criticized, interpreted, reinterpreted, and recontextualized—that is, submitted to the process of becoming absorbed into scientific knowledge.

have constraints more or less tied to the scientific results produced. The third, however, measures success not necessarily by the science produced, but by the perception among voters and constituents that they themselves might benefit from the particular funding. For government funding, the funding constraints are therefore much less pressing (the amounts potentially available through government taxation, borrowing, or money creation are huge), and they are the least connected with the success (in terms of usefulness to other scientists in follow-on research) of the scientific activity itself. These characteristics, compounded by the organization of the government funding apparatus into a small number of large bureaucracies, have potentially corrosive effects in several ways. We divide these effects, for ease of exposition, into incentive effects, "Big Player" effects, problems of boom and bust, and problems of bureaucracy.

Incentive Effects

Under government science, incentives matter, just as they do in markets. These incentives will affect the institutions involved in the administration of science, including funding agencies' recipient institutions, and also affect how scientists behave. Funding agencies are not autonomous, but operate as bureaucracies in the government. Their incentives emanate, at least in part, from the legislative and the executive branches, thereby establishing a political dynamic for explaining their behavior along any number of margins, including the areas of science that receive funds, the institutional recipients, and the patterns of geographic disbursement. Symmetry of interests exists between the funding agencies, including the military, and recipient institutions (industry and universities), which has implications for the dynamics of government science because it creates a potentially powerful lobbying nexus of parties whose interests are geared to sustaining and expanding government funding (Ikeda 1997).

A well-known example of such lobbying occurs in academic "earmarking": "a legislative provision that designates special consideration, treatment, funding, or rules for federal agencies or beneficiaries" (Savage 1999, 6). Academic institutions use their influence and lobbyists to secure appropriations for specific ("earmarked") university research projects or facilities. As table 2 shows, such funds averaged about $550 million per year during the 1990s and had tripled by 2002.

The enormous growth in academic earmarked funds reflects the increasingly significant influence of academic institutions in securing federal funding. As seen in figure 5, the growth in federal funding is principally accounted for by the funds allocated to academic institutions. In 2002, federal funds directed to academic institutions exceeded $22 billion. In addition, of the $11.5 billion allocated to federally funded R&D centers (FFRDCs), more than $7 billion went to the sixteen university-administered centers.[35]

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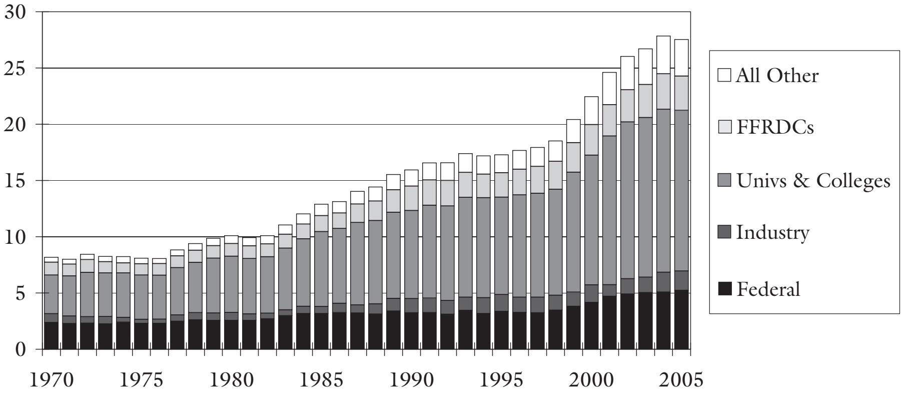
[35] NSF 2005b, table B-15, pp. 86–87. FFRDCs include such well-known facilities as Los Alamos National Laboratory (University of California), Jet Propulsion Laboratory (California Institute of Technology), Lawrence Livermore National Laboratory (University of California), and Argonne National Laboratory (University of Chicago). These four account for more than $5 billion of the $7 billion total.

Table 2
Funds for Congressionally Earmarked Academic Research Projects, 1980–2002 (millions of current dollars)

Year	Amount	Year	Amount	Year	Amount	Year	Amount
1980	11	1986	111	1992	708	1998	528
1981	0	1987	163	1993	763	1999	797
1982	9	1988	232	1994	651	2000	1,044
1983	77	1989	299	1995	600	2001	1,668
1984	39	1990	248	1996	296	2002	1,837
1985	104	1991	470	1997	440		

Source: National Science Board 2004a, 5–16.

Figure 5
Federal R&D Funding, by Type of Performer, 1970–2004 (billions of 2004 dollars)



Source: Association for the Advancement of Science 2004a. Based on NSF, Federal Funds for Research and Development Fiscal Years 2002. 2003. 2004 and Federal Funds Historical Tables. 2004.

A closer look at R&D expenditures at academic institutions for 2001 and 2002 shows that 67 percent of the total funds originated from federal, state, and local government (see table 3). Funding sources from academic institutions themselves accounted for nearly 20 percent of the total amount, and industry and other sources (principally nonprofit institutions) accounted for 6 percent and 7.4 percent, respectively. Most of these funds (59 percent) went toward research in the life sciences; the next largest allocations went to engineering (15 percent) and the physical sciences (8 percent).

Data on the use of funds by academic institutions from 1973 to 2004 show that the amounts for R&D in engineering, the physical sciences, environmental science,

Table 3
R&D Expenditures of Academic Institutions, 2001 and 2002

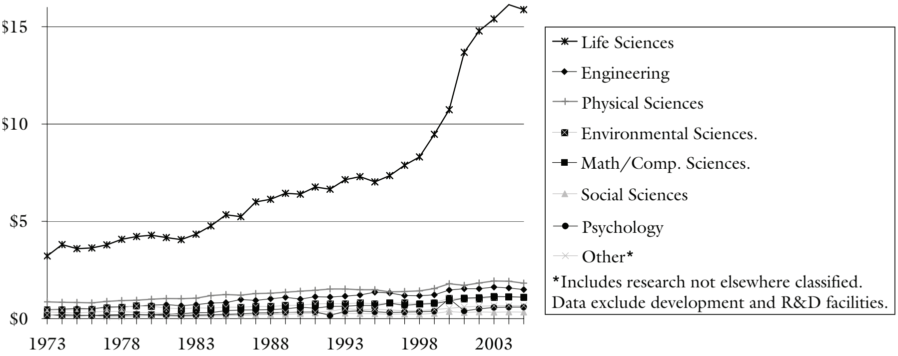
	FY 2001	FY 2002	% Change FY 01-02	% of Total (FY 02)
	R&D expenditures in millions of dollars			
by funding source				
Federal Government	19,213	21,834	13.6%	60.1%
State and Local Government	2,316	2,501	8.0%	6.9%
Industry	2,214	2,188	-1.2%	6.0%
Institutional Funds	6,587	7,109	7.9%	19.6%
All Other Sources	2,438	2,701	10.8%	7.4%
Total	32,767	36,333	10.9%	100.0%
by science and engineering field				
Engineering	5,007	5,504	9.9%	15.1%
Physical Sciences	2,805	3,008	7.3%	8.3%
Environmental Sciences	1,830	2,022	10.5%	5.6%
Mathematical Sciences	359	387	7.8%	1.1%
Computer Sciences	954	1,126	18.0%	3.1%
Life Sciences	19,213	21,404	11.4%	58.9%
Psychology	583	671	15.1%	1.8%
Social Sciences	1,440	1,583	9.9%	4.4%
Other Sciences, n.e.c.	577	627	8.8%	1.7%
Total	32,767	36,333	10.9%	100.0%
by character of work				
Basic Research	24,273	26,959	11.1%	74.2%
Applied Research and Development	8,494	9,374	10.4%	25.8%
Total	32,767	36,333	10.9%	100.0%

Source: NSF 2004, table 1-8, p. 58.

mathematics and computer science, psychology, and the social sciences have been rather stable over those thirty years. In contrast, the increase in R&D funding for the life sciences has been nearly sixfold. Figure 6 displays these trends.

Academic institutions' obvious success in securing substantial government assistance reflects a strengthening "partnership" between them and government funders. Although this development is justified in part on the grounds that nearly 75 percent of the R&D performed at academic institutions is "basic research," it also suggests

Figure 6
Federal Academic Funding Obligations, by Discipline, 1973–2004
(billions of 2004 dollars)



Source: American Association for the Advancement of Science 2006b. Based on NSF, *Federal Funds for Research and Development, 2004.*

that the direction and character of university science have become increasingly intertwined with government-determined priorities and oversight.

Scientists' success in securing funding testifies to their submission of proposals that receive a favorable hearing by the funding agencies. Thus, scientists have an incentive to develop and nurture professional relationships with agency members, advisors, and consultants. Finally, government funding of science, including that associated with military R&D, unavoidably establishes linkages between the funding agencies' preferences (or legislative charge) and the scientific activity that university and industry researchers perform. These linkages relate to the purposes for which funds are made available, thereby affecting the direction and regulation of scientific research as well as specific protocols for military R&D.[36] Greenberg (2001) does an especially good job of documenting this complex of interlocking incentives.

The mechanisms that funding agencies use to disburse funds reveal the significance of incentive effects. Although the earmarking of funds represents a somewhat peculiar means of allocating them, we suspect that in all practicable cases some sort of competitive or open solicitation of federal research monies occurs and that the method of selection entails a peer review process. Such mechanisms presumably help to keep science "honest" and "open." At the same time, however, the peer review process may entail certain undesirable consequences. Martino (1992, chap. 5) suggests that a bias against less-prestigious schools may exist. In 1984, he notes, the top twenty institutions received 46 percent of NSF funds (and provided 25 percent of the peer reviewers) and 44 percent of National Institutes of Health funds (with 30 percent of the reviewers). This distribution

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[36] Mukerji claims that the military directs classified research by controlling the scientists' access to research technology. Although scientists working for the military cannot publish their research, "they are able to get access to restricted information for their own use" (1989, 116).

does not prove bias, however, because the best researchers (in terms of citations) tend to work at the most prestigious universities, so it would be no surprise if funds allotted according to merit tended to favor these institutions. Nevertheless, even if peer review works as advertised, the unintended result is to strengthen the paradigms, models, and ways of thinking that currently characterize particular disciplines and distinguish the various disciplines from each other. This effect is an inherent by-product of having proposals reviewed by experts in the scientific area of the proposal. Although outsiders may see the peer review process as unfair, the implications of the process in terms of guiding the direction of science are a far more significant issue.

"Big Player" Effects

The source structure of science funding matters: an environment with a small number of large funders provides the potential for those who want to control the direction (or, in the extreme, even the content) of science to have systemic effects, whereas an environment with a large number of small funders more likely localizes and constrains the effects of individually power-oriented operations. This funding situation is the analog of the "Big Player" phenomenon in markets.

Following Koppl and Yeager (1996), we hold that government is a Big Player in science whose behavior is capable of dominating the flow of signals guiding the direction and intensity of scientific research. The magnitude of government's influence exposes science to self-reinforcing path-dependent processes that may be analogous to herding and bubbles in financial markets. However, unlike markets, where the prospect of self-correction is strong because underlying market realities prevail sooner or later, science has no analog of resource constraints for its products and has to rely only on its internal coherence as established by its own critical procedures. Big Player effects are known to produce herding and bubbles in financial markets. The corollary in science is the funding opportunities government provides for designated areas of research, such as AIDS or environmental issues.

Because such government-funded research enthusiasms are inextricably linked to the political process, the presumption must be that the direction of research is driven by the same incentives and constraints that drive other politically based funding programs. This consideration suggests that the basis for such funding is arbitrary and no more or less justifiable than any other possible use of taxpayer funds.[37] Moreover, the development of the direction of research itself is likely to be sustainable only for as long as the funding continues, after which new funding objectives will replace

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[37] Consider, for example, government funding for breast cancer and lung cancer. Lung cancers are the leading cause of cancer deaths in men *and* in women. Yet, since 2003, spending by the National Cancer Institute of the U.S. National Institutes of Health (under the Department of Health and Human Services) on breast cancer research, prevention, detection, and diagnosis has averaged $577 million per year, whereas spending for lung cancer has averaged $286 million. The mortality rate per 100,000 from lung cancers is more than twice that of the mortality rate from breast cancer. Even if these numbers were adjusted to reflect lung cancers for nonsmokers, federal research funding per capita for breast cancer would still be significantly higher. See National Cancer Institute 2005a and 2005b.

previous ones.[38] Government funding, in this sense, is not too unlike congressional omnibus transportation bills: a predictable amount of funding will occur, but for what and for whom is always up for grabs.

Problems of Boom and Bust

In recognizing that government science operates along a significant political dimension, we propose that the path of science also reflects the shifting funding priorities of government institutions. The amount of government intervention in science can be explained in part by public-choice considerations. Economists have long understood that the economy's cyclical activity or dynamic stability reflects the effects of central bankers' credit policies and perhaps representative democracies' electoral cycles. In economics, we can think of fiscal policy's effect on the average level of economic activity as opposed to monetary policy's effect on the system's dynamic stability. In proposing a similar kind of distinction for analyzing government intervention in science, our discussion considers such intervention in the context of the dynamic stability of science.

Windfall funding for science is like artificially cheap credit for business: the immediate effect is a growth in investment (including employment) and, with a lag, in output. The general quality of the output is not necessarily compromised, although by making it possible for people who would otherwise work elsewhere to pursue a scientific career, the tendency may be to lower the average quality of the practitioners. What may be noticeable is an increase in the irrelevance of the investigations pursued, in the sense that the resulting papers are of little or no interest to other researchers and generate few, if any, citations and follow-on publications.

In the distribution of government science funding, one would expect to see bursts of heavy funding in some areas, cutbacks or neglect in others, with the identities of these areas changing as the political winds change direction.[39] When the Russians threaten to lead the way into space, astronautics and space science is favored in the United States, building up an impressive edifice of research capability and trained scientists ready to push the discipline further. When the Japanese threaten to develop a "fifth-generation" computer, attention in the United States switches to computer science, and space-related science funding becomes insufficient to maintain the talent already developed. When the Japanese are no longer seen as a danger to national prestige, political attention wanders away from computer science, and employment for

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[38] We cannot discount the path dependencies that government-funded science will create. In the present context, it is possible that the prior existence of funding will establish an ongoing presumption of the value of continued funding in those previously designated areas on the basis of results that previous funding has already achieved.

[39] Such effects may be observable in changes in the spectrum of paper citations. A trend toward more published papers that receive very low numbers (particularly zero) of citations might be correlated with changes in funding amounts (specifically a lag). Zero-citation papers are the scientific analog of goods produced in excess of consumer desires. One would expect a period of lavish funding to be followed by an increase in the number of "useless" papers published and the reverse trend after funding downturns. Similar trends might be observed in journal start-ups and closings.

newer Ph.D. holders in the area of research for which they have been trained is much harder to come by than they had expected it to be. The scenario is one of localized booms and busts—"science cycles"—accompanied by the disruption of individual lives and the waste of talent and resources similar to that characteristic of business cycles.

Thus, temporarily unconstrained funding fosters unstable growth. Lavish funding results in more scientists being trained because the recipients of funds require assistants to pursue the funded projects; in turn, these assistants, if they are to become researchers in their own right, will require funding of their own.[40] Private funding sources, in contrast, naturally limit the growth of the system of science in a way that has a relatively direct connection to the perceived usefulness of the science itself to other scientists, and this sort of stabilized growth is likely to be more durable and productive than spurts of growth and retrenchment based on factors external to science.

The risk to quality of output and integrity of behavior comes with the downturns in funding, when the rate of increase of funding ceases to keep pace with the structural growth fostered by prior funding. Then, scientists compete with each other not merely for scientific reputation, but for their very livelihood.[41]

Problems of Bureaucracy

Concentration of funding in large government-financed organizations brings to bear the usual symptoms of bureaucracy: success measured by budget rather than by results, unwillingness to take risks that might subject the organization and its managers to criticism, and concentration on areas of research likely to be politically popular. As Greenberg (2001) notes, bureaucratic control of the funding process has led to conservatism (he calls it "calcification"). Although this result may not affect the general quality of research work, it tends to channel scientists who are seeking funding into more conservative, more obviously "acceptable" lines of inquiry and makes funding for mavericks more difficult.

Underlying many of these untoward effects is the classic "knowledge problem." As formulated by Hayek, this problem arises because centralized institutional arrangements make it impossible for planners to marshal adequately the relevant explicit and tacit knowledge dispersed among economic agents, leaving the planners limited largely

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[40] Changes in the number of trained scientists unable to find employment *as scientists* might be correlated with changes in the amount of funding. One would expect to find unemployment trends in particular areas within science characteristic of economic boom and bust. Even if science funding never decreased absolutely, unemployment increases should be observed after a slowing of the rate of increase below that required to fund adequately the new scientists who are minted in times of plenty. Because politically motivated funding tends to concentrate on particular areas of current political attraction, the analysis would have to be at the level of the discipline or subdiscipline.

[41] Although this outcome may be exceedingly difficult to document, reports of erosion of "scientific ethics" should increase during scientific funding recession and should decrease during scientific boom. Increases in "unethical" behavior driven by competition for funds would be the science analog of a scramble for loans at the height of a boom as business firms strive to complete projects in the face of resource scarcity or credit hardening. For a more standard economic discussion of fraud in science, see Wible 1998.

to their own personal knowledge in determining the allocation of resources.[42] As Hayek (1937, 1945) reminds us, it is precisely the knowledge peculiar to time, place, and circumstance, possessed by individual market participants but generating, via market interaction, a unique by-product—a constellation of market prices—that allows agents to engage in a process of rational calculation in implementing their plans.

Although science is not a market and does not produce market prices, it nonetheless shares several characteristics with a catallaxy. First, science is characterized by a division of knowledge in that any individual scientist knows only a portion of the existing knowledge in or germane to his own field. As scientific knowledge progresses overall, each individual scientist knows relatively less, even as his own increasingly specialized knowledge itself increases. Second, in the appropriate institutional setting, science has the capacity to function as an unplanned, complexly organized order. Thus, like the catallaxy, it functions as an emergent order capable of generating novel outcomes that arise as unintended by-products of the interactions among scientists. If we think of science as generating warranted knowledge in the form of definitions, theories, and empirical findings about reality, that knowledge is a snapshot of a mutable structure resulting from an ongoing process of appraisement and absorption of the individual contributions of past and current scientists.[43] Although constrained by the procedures scientists deploy, what emerges as scientific knowledge from the crucible of scientists' individual work is unplanned. Even if we may find it comforting to describe "truth" as an abstract goal of scientific activity, the specific content of that goal is something that can be discovered only as a by-product of the process itself. In this sense, science is end independent.

Attempts to plan science centrally, whether overtly or indirectly by monopolization of its funding, foster an institutional framework incompatible with science as a self-ordering and self-correcting order.[44] Planning's implicit (and no doubt unintended) aim is to remake science into a constructed order with particular ends specified in advance and resources directed so as to achieve such ends or to serve special purposes. This objective entails that government science tend toward dominating scientific activity both in terms of the specific allocation of scientific manpower and capital and in terms of the specific objectives that scientists seek to achieve. Underlying this tendency are two incorrect presumptions: first, that the planning board can somehow overcome the inherent division of both explicit and tacitly held knowledge within the scientific community to organize and direct science rationally, and, second, that in establishing specified goals for science and directing scientific activity toward those purposes, the planning board will not subvert the inherent discovery process associated with free science by reorienting science toward the generation of preordained sorts of knowledge. Even if one were to concede that free

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[42] See the essays on the socialist calculation debate by Mises and Hayek in Hayek 1935. See Lavoie 1985 for a more recent treatment.

[43] We have previously described this process in Hayekian terms as science generating a particular kind of *classification* over some specified domain of inputs in order to capture the adaptive characteristics of various knowledge-generating orders. See McQuade and Butos 2005; McQuade forthcoming.

[44] See Hayek 1973, chap. 2, and Butos and Koppl 2003.

science is subject to "market failure," it does not follow that interventionist (and centrally planned) science represents a coherent framework for correcting such putative failure.[45]

Another kind of knowledge problem also bears an equally and perhaps even more important connection with science. At the very foundation of what science is understood to be is the notion that it has the capacity to generate new knowledge. The circumstances and conditions that induce the creation of knowledge are bound up in the specific institutional arrangements that compose science and govern the sorts of interactions in which scientists engage. As noted earlier, science is a particular kind of order that generates as a by-product of scientists' activities something we recognize as "scientific knowledge." The principal characteristics of social orders such as science are their dynamic stability and adaptability, which allow them to function successfully as knowledge-generating systems. Yet, as we have seen, the structure of government funding of science has adverse implications for long-term stability and adaptability and therefore for the generation and use of scientific knowledge.

Conclusions

Government funding (and, by implication, its at least partial control) of science is widely claimed to be an appropriate function of government. We have presented arguments that dispute this claim. Valid analysis of science funding requires a perspective rooted in the actual characteristics of scientific activity and its institutional arrangements and, most important, in the characteristics of government funding activity and its institutional arrangements and their consequences. Our approach is geared to distinctions that we believe are crucial for understanding the real world. The standard "science as a public good" argument turns out on closer inspection to carry less significance than the early work of Nelson, Arrow, and others suggests. As Martin and Nightingale point out, work during the 1990s "has called into question many of the assumptions of the old economics of science, especially that science is a public good. . . . What is now generally accepted is that the conventional 'market failure' justification for the public subsidy is weak" (2000, xxii).[46] We find that the "new economics of science," though properly directing attention to the unique institutions of science, still falls back on the public-goods argument and on the uncritical acceptance of government funding mechanisms as the only viable means of science funding.

By any metric, the role of the federal government in funding science is significant. For example, expenditures for R&D in the United States are estimated to have been $276 billion in 2002.[47] Of this amount, the federal government accounted for

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[45] Machan also associates government science with the problem of rational allocation under central planning (2002, xiii–xx).

[46] It is significant that Martin and Nightingale's (2000) paper is the editors' introductory essay to *The Political Economy of Science, Technology, and Innovation* in the Elgar series International Library of Critical Writings in Economics.

[47] All reported data are from National Science Board 2004b, tables 4-4 to 4-7.

$78 billion (or about 28 percent), with about $24 billion allocated to federal government R&D, $17 billion to industry, and $27 billion to universities and colleges. Between 1953 and 2002, federal R&D expenditures (in 1996 dollars) increased from $5.3 billion to $70 billion, an average annual increase of 7.8 percent.[48] We believe such evidence supports our claim that government is indeed a Big Player in science whose funding decisions in terms of absolute magnitudes and the direction of R&D carry important implications for both the economy and science.

If the outlines of our analysis are accurate, then the problem has no political solution; further politicization of science, as Greenberg (2001) advocates, is like trying to put out a fire at a gas station with gasoline. The current system makes scientists' well-being dependent on the whims of political expediency. It creates winners and losers in the scientific community, where the winning is not necessarily based on scientific achievement, but on the ability to secure and maintain a flow of politically motivated funding. The only solution is for the political connections to be bypassed. Such circumvention is unlikely to happen as a result of initiatives from within science because the scientists most favored with government funding (those held up as the pillars of the scientific community) will naturally not want to forgo their political arrangements. A significant hope for such bypassing is that the trend in industrial support of science, in the form of the employment and funding of scientists in laboratories that are integral parts of profit-making firms, will continue to increase. Those in business have realized that scientific freedom and monetary profit are not necessarily incompatible in that scientists free to pursue their research into whatever interests them and free to publish the results of such research openly in normal academic outlets can still, through their expertise and specialized knowledge of the current publications in their field, contribute to in-house projects geared to creating revenue-generating products. Moreover, in certain areas, particularly in the biological sciences, access to findings prior to formal publication gives the firm a jump on the competition that can be profitable in itself.[49]

Such a provisional prognosis is sure to be controversial. We are only too aware that the topic of government funding of science is a large and complex one and, to make things more difficult, one more likely to be discussed in normative rather than positive terms. Our objective in this article and in future work is to provide a positive analysis of the effects of government funding on science and to illustrate the predicted effects empirically. Our basic approach, made evident in the current article, is informed by a model of science as an adaptive knowledge-generating order whose

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[48] Over the same period, nongovernment (industry, universities and colleges, and nonprofit organizations) funding of R&D increased on average by 26.6 percent per year, with the great majority of the absolute increase accounted for by R&D originating in industry and most of that increase (approximately 80 percent) since 1982. The evidence also supports the observation that government funding of "basic research," as defined in National Science Board 2004a, 4.8, has crowded out industry and especially university funding of research. See table 4-8 in National Science Board 2004b. Also, in this article, we have not taken account of state-level government funding of science.

[49] The history of the Human Genome Project, described in Shreeve 2004, is particularly instructive in this respect.

fundamental transactions involve publication, citation, and criticism. In the context of this basic social arrangement, we examine the effects of different regimes of funding. We insist at the outset that assessing such matters in terms of the theory relevant for a market process is not tenable: the market economy is characterized by a pricing process in a system of profit and loss based on enforceable property exchanges, but such features are absent from the knowledge-generating process of science. Science must be analyzed in terms of the incentives and transactions characteristic of science, not those characteristic of markets.

That government funding, with its presumably scientifically well-intentioned aims *and* its politically driven orientation, has significant implications for the kinds of questions scientists ask and for the kinds of knowledge they generate seems completely plausible. But provided that the standard critical institutions are in play, a scientific discovery has the same epistemological status whether it has been funded by the NSF or by a private patron. The problem, then, is that on the surface the specific characteristics of government-funded science and the knowledge it generates are not evidently any different from those that have originated through private funding.[50] We have suggested, however, that the effects are more subtle and that they affect the structure and function of the scientific arrangements themselves: government funding affects science in a way analogous to the ways price controls, subsidies, credit expansion, and central planning affect markets, and we have begun in this article to document an institutional structure in science that is made more unstable and maladapted to its environment as a consequence.

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[50] There are, of course, some notable exceptions to this claim. The Lysenko affair in the USSR, for example, involved the stipulation and enforcement of government-mandated truth—heavy-handedness that reflects an abandonment and suppression of the critical tradition in science. This fact, however, does not mean that the presence of such a critical tradition is a sufficient condition for avoiding such outcomes.

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