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Author: Roger G. Noll

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Federal R&D in the Antiterrorist Era

Roger G. Noll, *Stanford University*

Executive Summary

The President's budget proposals for fiscal 2003 envision that government R&D will play a substantial role in the War on Terrorism. The antiterrorism initiative could have two effects: to shift significant R&D resources to projects to fight terrorism, and to reconstitute the broad bipartisan coalition favoring all forms of R&D that has substantially weakened since the end of the Cold War. In practice, the President's budget proposals do not indicate either effect. The amount allocated for antiterrorist activities is minuscule, and the President's budget continues a long trend of rapid growth in biomedical research and stagnation or decline in nearly every other category.

I. Introduction

This chapter examines federal spending on research and development (R&D), and asks whether the recent antiterrorism fervor is likely to cause a substantial increase in R&D spending during the next few years. This question is potentially significant for two reasons. First, U.S. R&D is important for long-term economic growth throughout the world. From the perspective of the U.S., Federal R&D policy is important because U.S. economic growth depends on continued productivity advances and, especially, the health of American high-tech industries. For the rest of the world, U.S. R&D is important because the U.S. is by far the world's leader in R&D and technological progress, and improvements in U.S. technology tend to spread to other nations because technological progress tends not to respect political boundaries. Second, in the past, major long-term changes in national security priorities have had a major effect on Federal R&D spending that lasted for a decade or more. In general, the perception of a new threat to U.S. national security (e.g., the Cold War) has led to increased R&D budgets, while substantial involvement by the U.S. in military conflicts (e.g., Vietnam) has led to reduced R&D spending.

A substantial federal role in R&D has a long history, staring early in the nineteenth century. Since World War II, the U.S. government has been the world's most important single source of R&D spending. The fiscal 2003 budget continues this policy. The present (Bush II) administration proposes to spend $112 billion on R&D in FY 2003, which is likely to exceed total public and private R&D spending in any other country (the closest is Japan at around $100 billion) and to account for roughly 40% of the total U.S. R&D effort.[1] The results of this R&D cannot be confined solely to the U.S., but will affect the technology base of industries throughout the world. Consequently, the decisions of the Federal government regarding its R&D budget could have a substantial effect on the growth of knowledge and technical know-how not only in the U.S., but in the entire world.

The events of the fall of 2001 led to an intensification of interest in R&D to deal with terrorist threats. The FY 2003 budget devotes two chapters to antiterrorist programs, one under the rubric of "homeland security" and the other dealing with international aspects of the war on terrorism.[2] The R&D component of the budget also "focuses on winning the war against terrorism," including programs "to improve detection of biological and chemical threats . . . and . . . to improve aviation security technology."[3] Whether this budget emphasis is durable remains uncertain; however, if the new emphasis does usher in a new era of greater federal R&D spending, the remaining issues are whether these initiatives will be successful, how other parts of the federal R&D budget will be affected, and what effect these changes are likely to have on overall R&D effort, technological progress, and economic growth.

The key conclusions of this chapter are as follows. First, although the connection of antiterrorism with R&D thus far appears tenuous, if past experience is repeated defense-related R&D expenditures are likely to be substantially larger and to grow faster in the next few years than in the 1990s. Second, increased expenditures on defense-related R&D are not likely to cause a long-term reduction in other R&D. Indeed, most likely increased defense-related R&D will cause other government R&D to increase, not to decline, although this effect may be delayed for a few years. Third, the effect of these changes on technological progress and economic growth depends on whether other sources of R&D support will continue to grow, and while these expenditures are difficult to predict, there is danger that at least in some areas federal R&D will substitute for private spending. Fourth, if non-federal sources of R&D expenditures do continue to grow, within a few years the U.S. is likely to face a serious supply bottleneck in R&D, arising from the declining ability of the U.S. educational sector to produce well-trained scientists and engineers. Without attending to this problem, much of the increase in R&D spending is likely to be dissipated in increases in R&D costs, rather than increases in R&D output. If so, greater spending on R&D is unlikely to increase the rate of technological progress, and could reduce it if, as seems plausible, a disproportionate amount of increased spending is focused on areas of R&D with low payoff. The remainder of this essay provides the basis for these conclusions.

II. The Basic Economics of Government R&D Programs

A great deal of useful research has been undertaken on the question of whether the government can play a beneficial role in supporting research and development. A necessary place to start in assessing the likely consequences of plausible near-term changes in federal R&D policy is a review of the arguments in favor of a strong federal role, as well as the cautionary arguments about why government may not be able to succeed very well if it seeks to fill this role.

R&D Market Failures

The case for a strong federal role in supporting R&D is derived from two arguments: that R&D is an important source of economic growth, and that other sectors of the economy are not likely to undertake either as much R&D as is justified by its economic return to society, or the right balance of R&D across industries or between more fundamental and applied projects.[4]

The purpose of R&D is to produce useful new knowledge. A major area of economics research since the mid-twentieth century has been to measure the contribution of advancements in knowledge to economic growth. The consensus view is that half or more of the growth in per capita income in developed countries arises from advances in knowledge.[5]

Once new knowledge is produced, keeping it secret for the purpose of capturing all of the gains from its useful applications is both difficult and inefficient. Keeping new knowledge secret is inefficient because, once it is discovered, giving others access to it for the purpose of improving their own productivity usually is far cheaper than the cost of discovering (or independently rediscovering) it. And secrecy is difficult because successful commercial applications of the knowledge are likely to reveal some of the secrets to competitors. Moreover, if discoverers require financial capital from others to develop and produce applications, in the process of convincing potential investors to provide financial capital, the discoverer must reveal some of the secrets, thereby risking loss of control of the new knowledge. For this reason, firms are very reluctant to contract with other firms to perform R&D activities.[6]

If innovators face considerable difficulties in keeping useful new knowledge to themselves, the beneficiaries of their new knowledge include competitors, producers in other industries, and consumers who do not pay for all of the R&D that made these benefits possible. Empirical researchers have not yet achieved consensus on the magnitude of these *spillover benefits* (i.e., benefits to someone other than the innovator) from private R&D, but nearly all work finds that they are substantial, ranging from 25% to 75% of the total social benefits of R&D activities.[7]

If those who pay for R&D do not capture all of its benefits, too little R&D is likely to be undertaken by the private sector. For-profit firms will not undertake as much R&D as is socially desirable, because some of the profitability of firm-supported R&D will be dissipated by information leakage. Moreover, because spillovers do not respect political boundaries, lower levels of government will have an inadequate incentive to support research because some beneficiaries will live outside their jurisdictions.[8]

The degree to which spillover effects are important is likely to differ considerably across types of R&D projects. For example, intellectual property rights are much stronger in some technologies (e.g., pharmaceuticals) than in others (e.g., mechanical devices), implying that the disincentive to invest in R&D is likely to differ among industries. In most cases, advances in fundamental scientific knowledge cannot be protected by intellectual property rights, implying relative underinvestment in fundamental research in comparison with commercial products. These differences in the potential significance of uncontrolled spillovers imply that if the government seeks to encourage more R&D to offset the spillover problem, it cannot adopt a simple, across-the-board policy of subsidizing all R&D equally. Instead, it must vary the magnitude of the subsidy according to the nature of the R&D project.

Informational problems give rise to a second rationale for public support for commercial R&D, which is to improve efficiency in the market for investments in R&D-intensive firms (especially small startups).[9] The basic problem here is that people with innovative ideas may lack financial capital to undertake the R&D necessary to commercialize their innovation, whereas those with funds available for investments may be uninformed about these ideas. Venture capitalists can overcome this disadvantage only by devoting time and resources to learning about new technical ideas—in essence, by doing research—but innovators may be reluctant to assist them in gaining this knowledge out of fear that potential investors may steal their ideas.

The government can attack these potential failures in the capital market by creating programs to investigate new ideas and then to invest modest amounts in the best ones. Presumably innovators are less fearful that government bureaucrats will steal their inventions, and so will be more willing to share their ideas through a grant application. Venture capitalists can then use the assessments by government officials, as revealed by their grant decisions, as information about which firms have the best ideas and therefore offer the most attractive investment possibilities. In this case, the main value of the award to a firm may not be the cash received from the government, but the effect of having been given an award on the ease with which the firm can attract private investments. Of course, the validity of this argument depends on whether government agencies have the capability and incentive to identify technical ideas that venture capitalists will find attractive, which, for reasons discussed below, may not be the case.

A third rationale for government R&D arises from the market power of the federal government as a purchaser of some products. For example, the U.S. government is, by far, the largest purchaser of many defense products. Moreover, for defense products that are invented and produced by U.S. companies, whether the product can be sold elsewhere also is decided unilaterally by the U.S. government. Consequently, the U.S. government has considerable market power in acquiring many defense goods, such as major weapons systems.

If the federal government did not support private R&D in the defense sector, firms might not be willing to undertake much R&D on their own. The reason is that, once a major innovation is at hand, the government can exercise its market power by forcing down the price to the cost of production, without an adequate margin to recover preproduction R&D. Moreover, because the government is the sole purchaser of many defense systems, the success of a weapons system in the market depends on whether it serves the performance objectives of the government, which the government is likely to know with greater precision than any potential supplier. Hence, if the government controls R&D activity, it is more likely to get the products it wants. For these reasons, it is hard to imagine that the government would not play a central role in supporting R&D in defense, space, and other areas where it is overwhelmingly the dominant source of demand.

The final rationale for government R&D pertains to *externalities*—activities in which market incentives do not reflect all the social benefits and costs of an activity, even if the knowledge arising from their discovery can be retained by the innovator. An example is environmental pollution. Firms and consumers have little incentive to control their pollution unless government imposes regulatory requirements. If regulatory rules are based in part on the cost of abatement, polluting firms can expect that successful R&D on abatement methods will lead to more rigorous abatement requirements. As a result, polluting firms do not have an incentive to invent technologies that reduce pollution beyond the level required by regulation.

Whereas other firms may have an incentive to invent abatement technology in hopes that regulators will then force polluters to use it, this effect is not likely to offset the first disincentive, for two reasons. First, polluting firms are likely to know more about their production technology and product design than other firms, and so to face lower costs of inventing new abatement methods. Second, for abatement technology to succeed in the market, it first must be approved by regulators in a process in which the potential customers of the technology are likely to oppose its adoption, which is an additional costly step in the innovative process.[10] Thus, the pace of innovation to deal with externalities like pollution is likely to be slower than is socially optimal.

Problems with Government R&D Programs

The preceding arguments are based on the idealistic assumption that government seeks to correct inefficiencies that arise in markets, that it possesses the information necessary to determine how to correct these market failures, and that it can be effective in increasing total R&D

effort. Several cautionary observations about government-sponsored R&D question these assumptions.

Crowding Out One potential difficulty with government-sponsored R&D is that government dollars will simply substitute for private dollars as the source of support for R&D projects. The economics research literature generally supports the idea that this crowding out effect is present in some but not all cases.[11] Crowding out can arise for three reasons.

Labor supply constraints: If the economy is at full employment and all scientists and engineers are already fully employed in R&D activities, an increase in government R&D effort will redirect R&D into areas of lower private profitability but will not succeed in increasing overall R&D effort. Instead, the increase will cause higher wages of technical personnel and higher costs for R&D projects.[12] In principle, the shift in the composition of R&D could favor projects that have higher social productivity (taking into account benefits that do not accrue to the entity undertaking the R&D), but it will not solve the problem of general underinvestment in the search for new knowledge.

Eventually this effect can be eliminated if higher wages for technical personnel cause more people to become trained as scientists and engineers and then to seek employment in R&D activities. But an adequate response in the supply of technically trained workers is by no means assured. To begin, a labor supply response to rising wages is expensive and time-consuming because it requires substantial education. People are unlikely to switch career plans unless they believe that job prospects in technical fields have become permanently more attractive, rather than simply reflecting a temporary boom in pursuit of a transient priority. For example, people picking a career in 1950 plausibly were more likely to believe in the durability of the Cold War as a source of demand for R&D than contemporary young workers regard the durability of the antiterrorism crusade. Thus, the supply response is likely to be very protracted.

Even if labor supply does respond to growth in wages, the response is not likely to be adequate from a societal perspective. If investments in R&D provide economic benefits that exceed the returns to R&D investments, R&D workers in the private sector will be paid less than the value of their economic contribution to society. If other occupations generally have lower spillover effects, their workers will be paid wages that more nearly parallel their social productivity, and as a result the wage signals to prospective workers will induce too few people to pick a career in R&D. One can induce an adequate supply of R&D workers by only two means: subsidizing private R&D or subsidizing the training of R&D workers, such as by paying for their educational preparation.

In fact, the relative wages of college graduates in general and of technically educated workers, in particular, have risen significantly during the past twenty years.[13] As a result, the fraction of young adults who are enrolled in higher education has grown steadily. Yet the number of students with technical education is not increasing, due to still another barrier to a long-term response in labor supply.

A significant increase in technically trained workers requires that those who train scientists and engineers must expand their enrollment capacity. In practice, the ability to train more scientists and engineers is severely limited. To respond to growth in the demand for technical workers, students must receive adequate education in mathematics, science, and engineering, beginning in elementary schools and continuing through college. The poor performance of most American elementary and secondary schools in these areas has been a matter of public debate (but little effective action) for two decades. Because other nations, including some developing countries such as China and India, have generally done a better job in elementary and secondary education, an increasing fraction of science and engineering students in American higher education and new workers in American high-technology industries are foreign.[14]

While importing qualified foreigners has proved to be an important source of technical personnel, bottlenecks in science and engineering education among colleges and universities remain an additional barrier. American colleges and universities are the world's leaders in producing high-quality scientists and engineers, which explains why so many superb foreign students seek their higher education in the U.S. In Europe, enrollments in higher education have increased, but at the expense of educational quality, while developing countries lack the resources to train more than a relatively low proportion of their college-age students.[15]

In the U.S., most scientists and engineers are trained in public universities and colleges that are financed by state and local governments. As in Europe, these institutions have experienced growing enrollments in the face of declining real budgets, but they have responded somewhat differently. U.S. public universities have not expanded enrollments in technical fields, but instead have responded to the scarcity of financial resources for expanding faculty and laboratory space in technical fields primarily by rationing positions and raising prices (tuition and fees minus financial aid).[16] By the 1990s, the number of undergraduates who wanted to major in science and engineering was roughly 50% larger than the number accommodated.[17] Thus, increasing the number of high school graduates, domestic or foreign, who qualify for technical degree programs could simply increase the number of students who, once they reach college, are diverted into other fields that contribute less to economic growth but that are less costly to teach.

The implication of the preceding analysis is that during times of full employment, the primary effect of government R&D programs is to alter the composition of R&D rather than to increase the total. Without serious attention to increasing the supply of R&D workers, government R&D programs are not likely to solve the problem of general underinvestment in R&D by the private sector.

Reduced R&D profitability: The second cause of crowding out is that federal R&D, if successful, may reduce the private returns to R&D effort and hence the propensity of the private sector to spend its own funds on R&D. If federal R&D increases overall R&D effort in a productive manner, the result will be greater innovation across the board in the economy. Assuming that to some degree the products of federally financed projects compete with the products of privately financed projects, the last dollar spent in the latter category will produce less profit than it would have produced in the absence of the federal project. If firms invest in R&D to the point at which the returns to the last dollar equal the returns that are necessary to induce R&D investments, an increase in federal R&D will cause an offsetting reduction in private R&D.

Whether federal R&D is a substitute for private R&D depends on the circumstances. The preceding argument is most relevant for programs that attempt to advance technology in a particular industry by paying part of the cost of industry research consortia, such as the creation of Sematech to speed semiconductor development in the 1980s.[18] At the other extreme, the argument is least likely to apply to federal support for R&D that is most likely to produce advancements in knowledge that others will find easy to duplicate, and for fundamental scientific knowledge that itself has no direct commercial use, but that can be the basis for advances in commercial technologies and products. Thus, the primary implication of this danger of crowding out is that federal R&D will be more productive if it focuses on areas where R&D market failures are likely to be large.

Bureaucratic implementation: The last way in which crowding out can occur is through the way that the government evaluates its own success in R&D programs. A common method of evaluating a program is on the basis of the commercially successful products that emanate from it. In reviewing commercial R&D programs, Congressional overseers frequently ask for examples of commercial successes—new products, processes, and firms that have succeeded in the market after receiving a federal R&D contract. The problem with this approach is that it creates an incentive for agencies to sponsor the most commercially attractive projects —the ones that industry on its own has the most incentive to pursue. A study of the Small Business Innovative Research Program found evidence that Congress evaluates the program in part on the basis of examples of commercial successes, and that crowding did occur—firms that received an SBIR grant appear to have reduced their own R&D effort by approximately the same amount.[19] A less systematic review of the Advanced Technology Program contains several statements by industry and government officials that explicitly evaluate projects on the basis of commercial success, and others that express concern that the program is not sufficiently focused on solving market failures rather than being associated with commercial successes.[20]

This problem is similar to the previous source of crowding out in that it involves government R&D support substituting for private investments, but the mechanism and its cause are different. In this case, the problem arises from a propensity to pick projects on the basis of their probability of commercial success, which than can lead to supporting exactly the same work that the private sector would have been most willing to support on its own. An important source of this problem is the difficulty in evaluating the success of an R&D program. To do their jobs, Congress and the political appointees in the executive must make budget allocations across competing programs on the basis of their effectiveness. Yet the effectiveness of R&D that is motivated by the desire to improve commercial technology is difficult to measure in any way other than whether the program led to innovations. Identifying projects that are both commercially attractive and unlikely to be supported by the private sector because they have high spillover benefits requires far more information, technical knowledge, and effort than determining whether a project is likely to lead to a commercial innovation.

A necessary action to ameliorate this problem is to invest adequate resources in reviewing proposals and evaluating programs, as well as a clear statement of a program's mandate that emphasizes creating spillover benefits as opposed to commercial success. As a practical matter, programs have not been set up in this way, and evaluations of commercially oriented R&D programs rarely address, let alone seriously analyze, whether the program supports projects that solve spillover problems and complement the R&D efforts of firms in the industry, rather than substitute for private support.

Summary on crowding out: Independent research on the effect of federally supported R&D generally concludes that crowding out is a serious concern in two key respects. First, R&D policy needs to be paired with educational policy, especially policy regarding higher education in technical disciplines and math and science education in elementary and high schools. At the national level, there is a serious question of whether a large increase in federal R&D support during full employment will lead to more research. Second, programs that are designed to advance commercial technologies in specific industries have not been designed with sufficient precision to focus on projects with substantial spillover benefits to members of society other than the firms that undertake the project, rather than providing funds to successful commercial ventures.

Distributive Politics Another cautionary observation about federal R&D programs pertains to the accuracy of the assumption that these programs are designed and managed primarily to overcome market failures in R&D. The foundation for this argument is that economic inefficiency, *per se*, does not translate into political action. Instead, programs are shaped by the pattern of support and opposition that they engender among organized political constituencies.[21] Elected officials and civil servants, therefore, are likely to make decisions about the size and scope of R&D programs on the basis of their effects on the key interests that are likely to be affected by them, especially if those interests already are effective participants in the policymaking process. As a result, the design of R&D programs is likely to give considerable weight to the effect of a program on the distribution of wealth at the expense of its effects on the rate of technological progress.

If policy tends to be biased towards advancing the interests of existing organized groups, one effect will be for government to avoid projects that threaten an established industry, such as by providing funds to a startup or a firm from outside an industry for an R&D project that would radically alter the industry's technology base. In this case, government is more likely to support collaborative R&D that involves most or even all of the firms in an industry, but in so doing risks reducing competition and overlooking the most promising radical ideas, which historically have tended to come from outsiders. Another expected effect is that once a program has been initiated, killing it in the face of poor performance will be more difficult than it would be if the project were privately financed, because of the political significance of the lost jobs and failed investments that would follow cancellation.

The desire to avoid killing projects leads to still another problem—the tendency to avoid using a portfolio of projects when the most promising path of technological innovation is uncertain. The advantage of R&D competition among firms is that it provides a mechanism whereby several attractive technological approaches can be tested simultaneously. But innovation competition leads to swings in the relative fortunes of firms within an industry, as has been apparent through the history of the information technology sector since the invention of the transistor. Because political officials have an incentive not to be directly responsible for the failure of firms, they have an incentive to avoid the portfolio approach because it will create losers. Indeed, two government R&D programs that adopted the portfolio approach and that, initially, were quite successful in the 1970s (broadcast satellites and photovoltaic cells for electricity generation) were prematurely canceled when the technologies began to create losers.[22]

The Net Value of Government R&D

Research on the benefits and costs of government R&D certainly cannot provide a definitive conclusion on the overall net effect of these programs, but it has led to broad agreement on four points. First, government R&D does have a potentially useful role in many areas, especially in foundational research in science and engineering, where those who discover new knowledge are not likely to capture much of its commercial benefits. Second, abstracting from the additional problem of inducing technological progress in industries that supply products for the production of public goods (such as weapons systems and pollution abatement devices), the private sector is not likely to make adequate investments in R&D without support from the government. Third, large-scale support for commercialization of new technologies in the private sector is very likely to be inefficient because distributive politics is likely to distort project choices. Fourth, crowding out is a concern both for specific commercially significant projects and for the overall level of R&D effort in society. An important component of policies to ameliorate this problem is to expand the capacity of higher education to produce scientists and engineers.

III. Trends in the Federal R&D Budget

This section examines the correspondence of the size and composition of the federal R&D budget to ascertain the extent to which it reflects the arguments of the preceding section. The issues to be addressed are whether the pattern of expenditures is roughly consistent with the market failure rationales for public support, and whether program implementation leads to problems of crowding out and distributive politics. To address these issues, this section examines recent budget initiatives in the context of the entire postwar history of federal R&D policy.

Since the mid-1960s, federal R&D expenditures, after adjusting for inflation, generally have been rising, but less rapidly than either private R&D or the overall economy, as measured by the gross domestic product (GDP). Table 3.1 shows several indicators of federal R&D effort, broken down by defense and civilian (including space) programs. The table organizes the data by presidential administration in order to demonstrate the dominance of contemporary policy issues over partisanship in the level and composition of federal R&D effort.

An important caveat to these data, and the analysis to follow, is that the true effect of the Bush II administration on the R&D budget is still highly uncertain. Due to the natural timing of the budget cycle, the 2003 budget is the first prepared in its entirety by the Bush II administration. Moreover, this budget has yet to be reviewed and amended by Congress, as it surely will be. For several years, Congress has appropriated substantially more money for R&D than the President has proposed, so it can be misleading to compare past increases in spending to the Administration's proposals for FY 2003. Thus, the analysis to follow should be interpreted as where the Bush II administration would like to move federal R&D, and not necessarily as where it will actually go.

Table 3.1
R&D budgets by presidential administration

	Federal R&D budget					
	In bil. 1996 $		As % of GDP		As % of total R&D[a]	
Fiscal year	Defense[b]	Other	Defense[b]	Other	Defense[b]	Other
1953	8.1	1.5	0.4	0.1	48.0	5.9
1961	30.9	8.3	1.3	0.4	50.4	14.8
1969	30.8	27.2	0.9	0.8	31.3	27.2
1977	24.4	23.7	0.6	0.5	25.8	25.2
1981	27.6	28.1	0.6	0.6	25.4	21.2
1989	48.7	24.6	0.7	0.4	27.9	14.7
1993	43.0	29.8	0.6	0.4	21.6	15.0
2001	44.3	34.7	0.5	0.4	NA	NA
2003[c]	52.7	41.3	0.5	0.4	NA	NA

[a] These columns are for calendar years, not fiscal years. Unfortunately, recent data on private R&D are not available because the National Science Foundation did not complete its biannual report on R&D, *Science and Engineering Indicators*, for 2002.
[b] Includes some research programs outside the Department of Defense, most notably research on nuclear weapons in the Department of Energy, but does not include space R&D in the National Aeronautics and Space Administration.
[c] Proposed.
Sources: *Budget of the U.S. Government, Fiscal Year 2003: Historical Tables*, Table 9.7, p. 171, and National Science Foundation, *Science and Engineering Indicators 2000*, Appendix Table 2-19, p. A-48.

Defense-Related R&D

Federal R&D effort rose dramatically during the early years of the Cold War. Defense R&D expenditures (including space-related spending) roughly quadrupled during the ten-year period starting with the last two years of the Truman administration and continuing through the Eisenhower administration, then stabilized at this higher level during the Kennedy-Johnson administration. These increases reflected the high R&D costs associated with the development of strategic defense systems, nuclear weapons, and spacecraft. They also reflected a general political optimism about the utility of R&D, even basic research, in contributing to national security that reflected the success of military R&D during World War II.

Midway into the Kennedy-Johnson years and persisting into the Nixon administration, defense priorities shifted to conventional weapons and military operations associated with the war in Southeast Asia. Defense-related R&D peaked at $33.8 billion in 1996 dollars (1.2% of

GDP) in fiscal 1964, and then fell to $23.7 billion (0.6% of GDP) in 1976, the last year of fighting in Vietnam.

With the end of the war, defense R&D began to increase as attention focused on strategic weaponry associated with the Cold War, with the increase modest during the Carter presidency and then much larger during the Reagan administration. The big growth in defense R&D took place between FY 1983 and FY 1986, when constant dollar expenditures rose from $32.5 billion (0.6% of GDP) to $47.4 billion (0.8% of GDP), an increase of nearly 50%.

From FY 1986 through FY 1990, defense R&D stabilized, but with the fall of the Soviet Union and the new priorities occasioned by the Gulf War, defense R&D again plummeted during the G. H. W. Bush (Bush I) and Clinton presidencies, falling from a peak of $48.7 billion in 1989 to $38.4 billion in FY 2000. As a fraction of GDP, defense R&D peaked at 0.8% in FY 1988 and fell to 0.4% by FY 2000. The most recent defense buildup began late in the Clinton administration—the last Clinton increase ($5.9 billion for FY 2001) actually exceeded the first increase of the Bush II administration ($4.3 billion for FY 2002) and the proposed increase for FY 2003 ($4.1 billion).

The last fifty years provide some interesting perspectives on defense R&D. Despite the rhetoric of partisan politics, R&D spending really does not reveal a clear partisan effect.[23] Defense R&D effort is supported by presidents of both parties when an external military threat is salient but the nation is not deeply occupied with fighting a conventional war.

The two major recent growth spurts in defense R&D (1983–1986 and 2000–2003), while substantial, pale in comparison with the increases during the late Truman, Eisenhower, and early Kennedy presidencies. At its peak, defense R&D in the Reagan era accounted for a much lower percentage of GDP than it did during the Truman-Eisenhower-Kennedy period (0.8% vs. 1.3% in 1960 and 1.2% in 1964), and the change in this percentage during the later buildup also was far less (a growth of 0.3% of GDP under Carter and Reagan vs. a growth of 1.0% under Truman and Eisenhower that was maintained by Kennedy and Johnson until 1965). Finally, although the Clinton–Bush II increase in defense R&D has not yet run its course, it thus far has increased the percentage of GDP devoted to defense R&D by slightly less than 0.2 percentage points. The budget proposals for 2003 do not reflect the mobilization rhetoric of the war on terrorism.

Federal Nondefense R&D

In elementary economics textbooks, a conventional illustration of the principle of tradeoffs is the "guns or butter" metaphor: a nation's production can be imagined as requiring a sacrifice of consumer goods (e.g., butter) in order to obtain more national security (e.g., guns). Throughout the second half of the twentieth century and persisting through the FY 2003 budget of the Bush II administration, no such trade-off is apparent for R&D. In general, when defense R&D rises (or falls), so does nondefense R&D, although often one leads the other by a few years.

For example, during the defense R&D boom of the 1950s, the Truman and Eisenhower Administrations increased the percentage of GDP devoted to defense R&D from 0.3% in FY 1951 to 1.1% in FY 1961. In this case, a large increase in non-defense R&D (from 1.0 to 1.6 billion 1996 dollars) took place first, in FY 1950. Civilian R&D then stabilized at roughly 0.1% of GDP until the second half of the Eisenhower administration, when it rose to $8.3 billion (0.4% of GDP) by 1961. This growth in nondefense R&D continued until late in the Johnson administration, when it fell victim to the war in Vietnam, falling in FY 1967 and in nearly every year thereafter for a decade.

The only period in which federal defense and civilian R&D expenditures went in opposite directions for several years was during the Reagan and Bush I presidencies. Reagan clearly substituted defense R&D for other R&D, but the cuts in non defense R&D under Reagan were restored under Bush I, who cut defense R&D by a roughly the same amount as he increased civilian R&D. Nevertheless, together these two administrations actually increased both types of R&D programs, although the increase in defense was much larger. The Clinton Administration cut overall R&D spending in its early years when balancing the budget was its main priority, and then, in later years, as surpluses developed, substantially increased both defense and nondefense R&D. Finally, the Bush II administration has supported increases in both defense and nondefense R&D.

The Composition of Federal R&D

The composition of the federal budget provides information not only about the substantive priorities of the government, but also about the extent to which expenditures match the market failure arguments for

Table 3.2
Composition of federal R&D budget

	Percent of R&D Expenditures for:								
Year	Defense	Space	Science & eng.	Energy	Transport	Health	Agriculture	Resources	Other
1953	84	3	3	*	*	2	3	2	3
1961	79	7	3	2	2	4	1	1	1
1969	53	26	4	3	2	7	1	1	2
1977	51	16	4	10	3	8	2	3	3
1981	50	14	4	11	3	12	2	3	2
1989	66	7	4	4	2	12	1	2	1
1993	59	10	4	4	2	15	2	3	2
2001	56	7	6	2	2	23	2	2	2
2003P	56	6	5	1	2	24	2	2	2

Source: *Budget of the U.S. Government, Fiscal 2003: Historical Tables*, Table 9.8, pp. 172–178.
*less than 1%.

federal support. Table 3.2 provides the percentage breakdown of federal expenditures by broad functional categories for the past fifty years.

Defense and Antiterrorism As the table shows, most federal R&D money always has been spent on defense. The market failure rationale is consistent with a substantial federal presence in defense R&D. Since the Kennedy administration, every administration except that of Ronald Reagan has spent between 50% and 60% of the R&D budget on defense. The Reagan administration clearly differed from the rest, before or since, as defense R&D peaked at 69% of the federal R&D budget in fiscal 1986, a level that had not been exceeded since the Eisenhower era. Of the fall of the defense proportion by 13 percentage points since 1986, 3 points took place during the last years of the Reagan Administration, 7 points during the Bush I Administration, 3 additional points during the Clinton administration, and, as yet, none during the Bush II administration.

The antiterrorism initiative is an example of the defense procurement market failure rationale for government R&D in two respects. First, some R&D pertaining to antiterrorism focuses on technologies for which government would constitute most, if not all, of the demand. One example is antidotes for bioterrorism, for which a large part of the demand is for military and emergency relief personnel. With the federalization of airport security, another example is technology for detecting weapons hidden on passengers and in luggage. Second, strategies to protect against terrorism provide a public good—that is, the beneficiaries include a much larger universe of people than the industries, such as airlines, that might be the target of an attack.

The primary issue raised by the antiterrorism initiative is whether it is likely to involve a significant amount of R&D. The FY 2003 budget contains strong references to antiterrorism as a motive for reallocating research priorities, but only as a possible future priority. "Potential antiterrorism R&D applications span a wide range, including safeguarding the mail, developing new vaccines and air safety systems, and creating advanced materials and enhanced building designs. . . . Often, the scientific community will be asked to devise solutions in cost-effective ways that do not impinge on our way of life."[24] The budget goes on to report the creation of an interagency committee "to develop a coordinated interagency R&D plan for antiterrorism."[25]

Nevertheless, whether the antiterrorism campaign is likely to involve substantial R&D activity remains uncertain. The budget asks for $2.4 billion for R&D associated with antiterrorism.[26] Among the new initiatives, the budget lists $1.75 billion for bioterrorism research in the National Institutes of Health,[27] $420 million for the Department of Defense for threat detection, protective gear, vaccines, long-range surveillance to detect the delivery of weapons of mass destruction, and "hard target" munitions,[28] and unspecified sums for the Department of Transportation for airline security.[29]

The gross expenditures on these items substantially exceed the increase in net spending. Research on improving airline security systems and detecting and treating anthrax and other possible biological warfare agents has been under way for a long time. The most recent R&D budget analysis for the American Association for the Advancement of Science estimates that the antiterrorism R&D budget was about $900 million in FY2001 and $1.5 billion in FY 2002,[30] indicating that the net increase occasioned by 9/11 was at most $1.5 billion. Moreover, even the gross FY 2003 proposal is small compared to the total budget for R&D (about 2%) and even compared to spending on health R&D (about 10%). Thus, as yet the antiterrorist initiative contains relatively few dollars, and does not appear likely to be more than a small component of the general trend towards increased defense R&D that has been apparent for several years.

The defense R&D budget contains substantial expenditures to support the development of commercial technologies that are used extensively by the Department of Defense (DOD). Much of this work is targeted at either the aerospace industry or the information technology sector. For example, programs to develop high-speed orbital aircraft and to advance integrated circuit technology were financed by DOD. These activities are not clearly justified by the rationale that the government is the sole or major source of demand for them, but instead are more closely tied to the rationale that generally the private sector will underinvest in R&D.

Fundamental Research The market failure theory is consistent with substantial spending on fundamental research in science and engineering. In table 3.2, these expenditures are contained primarily under the heading "Science and engineering." This heading contains the R&D budgets of the National Science Foundation (NSF) and the general nuclear science component of the Department of Energy (DOE), which is dominated by research in the nation's particle accelerator facilities. The NSF research support budget has been increasing more rapidly than the rate of inflation since fiscal 1997, and has grown from $2.57 billion to a proposed $3.09 billion (nominal dollars) in the past two years. The nuclear science budget in DOE tripled during the last few years of the Clinton administration, and is proposed to grow from $2.29 billion in FY 2001 to $2.49 billion in FY 2003, which is slightly faster than inflation.[31]

Fundamental research is contained in the other categories, especially space, energy, and health. NASA includes a significant budget for space and earth sciences, which covers research conducted on various spacecraft as well as other fundamental research that is related to the development of space transportation, including biology in the space environment. Together these programs are proposed to grow from $4.75 billion in FY 2001 to $5.92 billion in FY 2003. The Department of Energy supports research in all sciences and engineering that pertains to energy sources other than nuclear, and the total DOE proposed budget for science and technology in FY2003 is $3.29 billion—about $800 million more than the nuclear research program.[32]

The health R&D budget includes a very large expenditure on basic research in molecular biology by the National Institutes of Health. Both the Clinton and Bush II administrations have been extremely generous with NIH, together doubling the NIH budget in five years between FY 1998 and FY 2003, with the last step a proposed increase of $2.9 billion to $24.1 billion.[33]

With the exception of NIH, the budget for fundamental research has accounted for a relatively stable share of federal R&D for the entire period. Health research has been the fastest-growing part of the R&D budget, and is the only component that is expected to increase its share of overall spending in the proposed fiscal 2003 budget. Between fiscal 2001 and the proposed FY 2003 budget, R&D expenditures increase by $20.5 billion, and of this $11.5 billion is for defense and $6.5 billion for health, leaving only an increase of $2.5 billion for everything else—which is insufficient to keep up with inflation.

This pattern of R&D expenditures closely parallels the composition of changes in the R&D budget during the second term of the Clinton administration, in which total R&D expenditures rose by $15.3 billion, with increases of $8.2 billion for defense and another $8.2 billion for health. Space, energy, and transportation all suffered major budget cuts during this period, while science and engineering increased by $2.1 billion. The Bush II administration's FY 2003 budget seeks to restore only a small proportion of these cuts.

The budget allocations for fundamental science and engineering during the past fifty years raise the issue of whether the steady increase in biomedical research is justified. Usually the criticism of the growth in the share of health in overall R&D takes the form of questioning whether the budget is "balanced"—that is, whether it is efficiently spread among areas of research by discipline, applied vs. fundamental, and areas of potential applications. The most common specific complaint is that the federal government has given insufficient attention to information technology and the fields of science and engineering that support it, while some scientists also complain that the government is too concerned about identifying specific applications that might arise from basic research and insufficiently excited about simply advancing human understanding of the natural world. In reality, these complaints do not appear to be generally valid, but some elements of the balance issue are genuine concerns.

The federal government has played a major role in both fundamental and applied research for four major sectors of the economy: biotechnology (primarily through NIH, although historically through the Department of Agriculture), aerospace (primarily through DOD and NASA), energy (primarily through DOE), and information technology (primarily through DOD and NSF). In each area other than biotechnology, the long-term changes in the level of federal R&D support are understandable.

The importance of aerospace has been diminished by the end of the Cold War, and the industry has shrunk dramatically. While one can debate exactly how much aerospace R&D ought to shrink, given the radical change that has occurred in international relations, the reduction that has occurred is within the range of defensible outcomes. After suffering a substantial decline at the end of the Cold War, support for defense-related research in information technology has recovered. Because of the importance of information technology in advanced weapons systems, substantial support from the Department of Defense for R&D is a reasonable consequence of the larger decision to pursue "smart" weapons for conventional warfare.

Support for fundamental research that is related to nuclear energy (mainly, support for particle accelerators) always has had a tenuous connection to applications, and after years of ups and downs, appears to be rising again. This research is very expensive, and particle accelerators have some important applications, but its justification depends mainly on the kind of knowledge it creates. Accelerator research attacks the most fundamental questions of all about the nature and origins of matter, and as a result advances in this area receive considerable public attention, and certainly among scientists bring great professional prestige. Because of the peculiar nature and value of this work, it is difficult to make a strong case in favor of a major change in the budget in either direction. Thus, the "imbalances" that have developed in the past few years through changes in the pattern of expenditures outside of the health area, while controversial, are not irrational.

Nevertheless, the balance debate reflects a valid concern: whether the explosive growth in biomedical research is justified. The growth in biotechnology R&D related to health raises an important issue with respect to crowding out: is the rapid growth in this area causing increased R&D effort, or is it simply driving up the cost of biomedical professionals, including clinical physicians on the boundary between research and practice? Likewise, is this R&D producing health benefits that are proportional to its growing cost, or is it mostly yielding new medical technologies with high costs and low benefits? To my knowledge, the research on R&D provides no definitive answer to these questions. One relevant fact is that the number of biomedical researchers associated with universities has grown rapidly while the numbers of other science and engineering researchers and clinical physicians in general practice are stable or declining. Another is that health care expenditures have been growing very rapidly for forty years while mortality and morbidity have not been significantly reduced for more than a few diseases. These broad trends are enough to justify a more serious investigation of whether the growth in biomedical research is mainly causing a substitution of effort in favor of research with a low social payoff and inflation in both biomedical R&D and health care costs.

Another important issue with respect to fundamental research is its apparently growing tendency to be affected by distributive politics. Most federal expenditures on fundamental research go to universities. Historically, the preferred method for picking university research projects was the system of peer review, in which researchers in a field evaluate research proposals and agencies generally support the projects with the most favorable reviews. In recent years a rapidly growing pool of research money has been earmarked for specific projects and specific institutions.[34] Between 1996 and 2001, the amount of academic earmarks in the final budget passed by Congress rose from $296 million to $1.668 billion, and the fraction of Federal expenditures on research at colleges and universities that was accounted for by earmarks rose from 2.5% to 9.4%.[35] Interestingly, academic earmarks account for a very large proportion of federal R&D that is directed at a particular external performing institution. In FY 2001 the total amount spent on earmarked projects was $1.766 billion, leaving only about $100 million outside of academia. With few exceptions, the earmarked projects are for institutions that are not highly regarded as either educational or research institutions.[36]

Support for Commercial Applications R&D performed by industry experienced substantial growth in the 1990s, roughly doubling between 1992 (the end of one recession) and 2001 (the beginning of the next recession); however, as is normal during a recession, real R&D spending by industry declined slightly between 2001 and 2002, and is expected to do so again in 2003.[37]

Support for industry R&D takes two forms. One is general support that is not aimed directly at a specific firm or industry, and the other is targeted support that takes the form of contracts with firms or industry consortia to undertake R&D.

The two leading examples of general support are fundamental research and the R&D tax credit. One stated motive for Federal support for fundamental research in science and engineering is to create opportunities for commercial applications, but most of this work is undertaken in universities, nonprofit research institutions, or government laboratories without any involvement by, or even specific application for, an industrial group. The R&D tax credit provides tax relief to firms that increase their R&D spending, and so provides indirect subsidies for R&D among firms that are profitable and so can use the tax credit. The evidence indicates that this tax credit has had a modest but significant effect on industrial R&D.[38]

As is apparent from the rest of the entries in the table, the presence of the federal government in R&D that focuses on specific industries and technologies other than health and defense is extremely limited. Two temporary surges in other types of targeted R&D expenditures have taken place: space and energy. The boom in the space program reflected the 1960s race to the moon and the 1970s development of the Space Shuttle. At the time of the moon landings, space accounted for about one-fourth of federal R&D, but since then has steadily fallen to the proposed 6% in FY 2003. The other temporary boom occurred in the 1970s for R&D on energy technologies in response to the two oil crises of 1972–1973 and 1979–1980. Federal support for research on energy technologies exceeded 10% percent of federal R&D at its peak in the early 1980s; however, it now accounts for only about 1%.

Across all agencies and categories, about a third of the R&D budget is spent through contracts with industry, most of which is accounted for by defense. Less than 15% of R&D performed by industry is paid for by the federal government.[39] Thus, in an economy that spends over $200 billion on R&D, only a few billion consists of targeted subsidies to deal with the general propensity of the private sector to underinvest in R&D outside of defense. Hence, it is reasonable to conclude that this particular market failure has not motivated much of a policy response, and that outside of academia and defense, the distributive politics motive for R&D spending does not have much of an effect on the allocation of R&D resources.

During the 1980s, a modest boom took place in programs in which the federal government directly supported a large number of commercial R&D projects, sometimes in industrial laboratories and sometimes in collaborations between federal and industrial researchers. Examples including the Cooperative Research and Development Agreements (CRADAs) between Federal labs and industry, the Advanced Technology Program (ATP) in the National Institutes for Science and Technology in the Department of Commerce, and support for industry-wide R&D consortia, such as Sematech for the semiconductor industry.

During the Clinton Administration, these programs generally experienced declining budgets and had mostly disappeared by the time the Bush II administration took office. For the most part, this category of programs is regarded as having at best mixed success, with the major problems being its susceptibility to pork barrel politics and the difficulties facing agencies in identifying projects that deserve federal support.

The FY 2003 budget proposal calls for the virtual dismantling of ATP. The new spending authority for ATP is proposed to be cut from over $100 million to $35 million. Because this program has been popular with Congress and is regarded as the best-designed of the various programs for supporting commercial R&D, this proposal may not be accepted by Congress.

R&D-Related Education Support for education in science and engineering fields can increase overall R&D and reduce the extent to which federal R&D causes crowding out of private R&D. The FY 2003 budget proposals provide for an increase in federal spending on education, including spending on mathematics and science in elementary and secondary schools and on support for college students, both generally and in science and engineering.[40] Whereas these increases are consistent with the argument in favor of subsidizing R&D by subsidizing the education of those who perform it, they amount to very little of the total spending for education. Federal expenditures account for only 7.9% of elementary and secondary education, and while the proportion is much larger for higher education, almost all of the latter is accounted for by Pell grants (proposed to total $10.9 billion in FY 2003), which provide financial support to students from low-income families regardless of their field of study.[41]

To change significantly the pattern of enrollments in higher education would require two major changes in federal policy. First, federal support would have to differentiate among students according to their field of study, providing greater support for students in science and engineering than for students pursuing other majors. Second, the additional support would need to be channeled towards increasing expenditures by institutions of higher education in these fields of study, either by introducing differential tuition rates or by providing grants to subsidize faculty, classrooms, laboratories, and other educational inputs in technical disciplines. The budget does not mention, let alone seriously contemplate, any such changes.

Conclusions

The preceding analysis leads to the conclusion that the reduction in federal R&D occasioned by the end of the Cold War appears to have come to an end. Both defense and nondefense R&D are once again growing. Moreover, despite the political rhetoric, this trend seems to have virtually nothing to do with the new war on terrorism. The growth in R&D spending began several years ago, and as yet the events of the fall of 2001 have had almost no effect on the composition of the federal R&D budget.

If an antiterrorism effect does arise, the effect may well be negative rather than positive. If (as thus far seems likely) the response to terrorism does not have a substantial, across-the-board R&D component, then the main effect of the war on terrorism will be increases in conventional budgetary line items. If these become large, the circumstance will come to resemble the budgetary environment during the war in Vietnam, when all forms of R&D spending took cuts. But for this to be the case, antiterrorism policy must have a major, durable effect on the budget, which, to date at least, does not appear to be the case.

Criticisms of the balance in the composition of the budget appear to be overdrawn. In reality, the relative emphases on fundamental vs. applied, and among areas of research, do not seem to have changed a great deal through several administrations. If one criticizes the Bush II administration for an overemphasis on biotechnology and defense, one must also level that criticism at every administration since Carter—with the exception of Bush I.

The federal government's priorities do not perfectly track those that would be derived from the basic economics of R&D, but they are not wildly inconsistent, either. While the correct magnitude of support for fundamental research and defense R&D is surely debatable, the historical emphasis on these areas is based on valid arguments about failures in the market for R&D. The relative paucity of applied research to support commercial technologies in most other areas is not consistent with the argument that the private sector is likely to underinvest in R&D; however, the problems with regard to political distortions in targeted subsidies for industry weaken the case for a major federal role.

Indeed, the primary problem with existing federal R&D programs probably is distortions arising from distributive politics, as witnessed most recently by earmarking for university research projects. But while this specific example is new, it is hardly exceptional. Distributive politics has interfered with the efficient implementation of federal R&D for a very long time. One might rephrase the issue as why Congress took so long to do to university research what it has been doing to many other programs (not just other R&D) for decades.

Notes

1. OMB (2002), Chapter 8, "Research and Development," pp. 159, 163.

2. Ibid., "Protecting the Homeland," pp. 15–24, and "Winning the War Against Terrorism Abroad," pp. 25–30.

3. Ibid., p. 159. The budget does not state the magnitude of either the level or the change in expenditures that focus on antiterrorism and homeland security, although, as discussed elsewhere in this paper, it gives a few concrete examples.

4. This section summarizes a very large literature that has become part of the modern economics canon. For a more complete statement, see Cohen and Noll (1991, chapters 1, 2).

5. See, for example, Denison (1985) and Lau (1996). Lau also finds that technological progress apparently has played virtually no role in economic growth in developing countries and the newly industrializing nations of the Far East.

6. For example, see Monteverde and Teece (1982).

7. For a summary of this research, see Griliches (1992).

8. The U.S. government, too, will have too little incentive to pursue R&D to the extend that other nations derive benefits from U.S. R&D effort; however, the extent of underinvestment will be lowest for the U.S. federal government among all governmental sources of R&D. The reason is that the largest single economic unit in the world is the U.S., so it faces less disincentive from spillover benefits than any other government.

9. See Lerner (1999).

10. An attraction of incentive methods of pollution abatement, such as emissions taxes and tradable emissions permits, is that they do create an incentive to advance abatement technology. However, most environmental and safety problems make little or no use of incentives, relying almost exclusively on traditional regulatory standards.

11. See Hall, Toole, and David (2000).

12. See Goolsbee (1998).

13. See Burtless and Noll (1998, pp. 63–85).

14. Ibid., pp. 73–81.

15. See Noll (1998).

16. See California Council (1999) and Cohen and Noll (1998).

17. See Romer (2000).

18. For a discussion of how federally-supported industry consortia can reduce overall R&D effort and slow economic growth, see Cohen and Noll (1994).

19. See Wallsten (2000).

20. See Wessner (1999).

21. For a more complete development of this argument, see Cohen and Noll (1991, Chapter 4).

22. See Cohen and Noll (1991, chapters 7, 11).

23. A table organized to reflect the partisan composition of Congress would not change this conclusion, although the evidence is less interesting because of the greater dominance of Democrats in Congress. Republicans controlled both houses of Congress only during the last six years of the Clinton Administration, when both defense and civilian R&D increased. The massive increase in defense coupled with a fall in civilian R&D under Reagan took place when the Republicans controlled the Senate but the Democrats controlled the House, and the recent increase in both types of R&D supported by the Bush II administration also is taking place in a period in which the partisan control of Congress is divided. In all other periods, both houses of Congress were controlled by Democrats.

24. See OMB (2002, p. 164).

25. Ibid., p. 164.

26. Ibid., p. 19.

27. Ibid., p. 165. Most of this proposed increase is for the development of diagnostics and treatments for biological warfare agents, but a small amount is for improving laboratories coping with biological or chemical incidents (p. 19).

28. Ibid., pp. 19, 166–167.

29. Ibid., p. 168.

30. See Flanagan and Turner (2002).

31. Historical Tables, OMB (2002, p. 178).

32. Ibid., p. 136.

33. Historical Tables, Ibid., p. 178. New obligation authority is proposed to increase even more, by $3.9 billion, to $27.2 billion (ibid., p. 143).

34. For a detailed description of the growth of the "academic pork barrel," see Savage (1999).

35. See OMB (2002, p. 162).

36. Ibid., p. 174.

37. See Armbrecht (2002).

38. See Hall and van Reenan (2000).

39. See National Science Foundation (2000), p. A-23.

40. The overall increase in support for science and engineering education at colleges and universities also reflects a considerable shift in the allocation of this support among agencies, with NIH and NSF receiving large increases and other agencies experiencing large cuts. For a more complete discussion of the education budget, see Jesse (2002).

41. Ibid., pp. 43, 46.

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