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Public R&D and social challenges: What lessons from mission R&D programs?

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1. Introduction

Societies today face a number of formidable challenges, many of them global in scope. These include adverse climate change, devastating diseases that are not yet under control, uncontrolled population growth in many low-income countries combined with stagnant or declining populations in many high-income economies, rapid urbanization in low-income economies that places stress on the provision of public services, and others. Although the development of new technologies alone will not solve any of these problems, for some at least the creation and adoption of more effective and appropriate technologies is a necessary part of any solution. It is also evident that market forces alone cannot induce all of the R&D investment that is needed for these solutions, and that government programs to aid in the development and deployment of the relevant technologies are needed.

In response to these challenges, a number of policy experts and policymakers have argued for public R&D programs structured similarly to the U.S. government-sponsored Manhattan Project or Project Apollo.[1] Reflecting their focus on the achievement of specific objectives in support of governmental goals, these historic programs are examples of a much broader class of publicly funded programs in "mission-oriented research." Although the proposals for a "new Manhattan or Apollo project" generally focus on public responses to climate-change challenges, similar mission-oriented initiatives could attract support in responding to other global challenges such as those mentioned earlier.

We have two motives for organizing this special issue of *Research Policy* on mission oriented public R&D programs. First, we believe Manhattan and Apollo are not the right models for new programs aimed at the challenges we now face. Nevertheless, mission-oriented R&D programs can be of great value if they are well designed to fit the particular challenge and the context. Second, we believe that familiarity with a range of existing mission oriented R&D programs can provide useful guidance for the design of new programs aimed at these challenges. The papers included in this special issue can help provide that familiarity, including an understanding of the factors that have influenced the design and goals of these different programs, and contributed to their successes and failures.

In spite of the historic size and importance of many central government mission-oriented R&D programs within the OECD, current discussions of R&D policy responses to today's social challenges have proceeded with little awareness of these programs, except for Manhattan and Apollo. Much of the economics literature on these policy issues focuses on public support of R&D as a response to "market failures." Although market failures are clearly present in many of the current challenges, economists have tended to overlook the significance of R&D support programs that are focused on specific objectives, in spite of the size and significance within most industrial-economy public R&D budgets of these programs. More generally, scholars writing about science and technology policy have largely focused on measures intended to stimulate overall economic growth. And scholars doing research on the role and nature of public R&D in support of particular sectors and objectives like national defense, or public health, or agriculture have tended to publish their work in specialized journals that are unfamiliar to most readers of *Research Policy*.

The societal challenges that have triggered recent calls for expanded public support for R&D are very diverse, and the design of a program concerned with any of these challenges must take into account the specific characteristics of the challenge and the

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[1] See Jacobson et al. (2005); Talbot (2006); or DiPeso (2009), all of which argue that similar mission-oriented R&D programs are an appropriate response to new global challenges.

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context within which technological responses will be developed and deployed. In spite of this diversity, however, the societal challenges highlighted earlier share a common characteristic – they are all very different than the challenges faced and met by Manhattan and Apollo. These programs were aimed to develop a particular technological capability, and the achievement of their technological objective signaled the end of the program.

Almost all of today's challenges are broader in nature and require efforts that are structured for the long run. Another key contrast stems from the fact that the user of the technologies that Manhattan and Apollo created was the government agency that funded the work. Most of today's challenges will require the actions of many parties, private as well as governmental, many of whom may provide little if any R&D funding, yet who will decide whether or not to deploy new technologies created by such initiatives. And unlike Manhattan and Apollo, new technologies developed to meet many current challenges will have to compete with technologies that already are in use and that have the support of powerful economic interests. Finally, all of the funding for the R&D in the Manhattan and Apollo programs was provided by the federal government. But for current societal challenges, publicly funded R&D, although vital, will be only one of a number of sources of R&D investment. In particular, private funding will be essential to both technology development and the necessarily widespread adoption of technological solutions.

The papers in this special issue examine mission-oriented R&D programs in health, agriculture, energy, and defense, while others focus on specific policy instruments that are common within many mission-oriented R&D programs. The mission-oriented R&D programs in defense, agriculture, health, and energy with the partial exception of defense-related R&D, are themselves quite different from Manhattan and Apollo. None of these mission-oriented R&D programs will serve as a perfect model for the program design needed for dealing with the present challenges, although some elements of these programs may be useful components of future mission-oriented R&D programs. But knowledge about these kinds of programs, the basis for differences in their contrasting design, and their apparent strengths and weaknesses, can inform thinking about how to deal with the various challenges.

2. Summaries of the papers in the special issue

Our discussion above stressed the diversity among mission-oriented R&D support programs. These programs differ in the nature of the mission, the kinds of R&D that are supported, the institutional characteristics of the R&D performers, and the intended principal beneficiaries. The first three case studies in this special issue are concerned with defense R&D, support of agricultural R&D, and the research support programs of the U.S. National Institutes of Health. The differences across these programs are as striking as the similarities.

As David Mowery points out, in the United States, Great Britain, France, and a number of other countries defense R&D is by far the largest government funded R&D program. In all of these countries the funding is done by the agency responsible for national security (in the United States, the Department of Defense). Although defense R&D programs span a very wide range of scientific and technological fields, and in many cases include some fundamental research, in the U.S. and in most other countries the lion's share of defense R&D is spent on the development of weapon systems. In almost all cases the government agency itself is the procurer and user of the systems whose development has been supported by defense R&D. In the United States at least the Department of Defense historically has adopted a long time horizon in managing its weapons development in peacetime. This means that, in addition to R&D spending supporting weapons currently or prospectively in use, it often funds R&D aimed to make future weapons possible, and to provide knowledge to help it decide what kinds to try to develop and ultimately to procure and use. In the United States, since 1945 the DoD has been the principal supporter of scientific research, and often graduate training, in a significant number of fields. DoD R&D investments have been especially significant within the U.S. national innovation system because the lion's share of this R&D has been performed by U.S. firms and universities.

Many U.S. and non-U.S. students of the Defense Department's large postwar R&D programs argue that these have effectively operated as a surreptitious "industrial policy," generating technological advances that supported the growth of leading U.S. aerospace, computer hardware, electronics, and other high-technology firms. By supporting technological advances with both defense and civilian applications, according to this argument (which has received some support in recent WTO rulings in trade disputes between the Boeing Company and Airbus over subsidies), U.S. defense R&D aided the growth of the postwar U.S. high-technology sector. The scale of U.S. defense-related R&D, as well as the fact that it has been allocated largely to industrial or academic research performers that themselves competed for funding, have aided in such technological "spinoffs." But these "spinoffs" have never been an important objective of U.S. defense R&D spending.

While defense R&D is special in a number of the characteristics mentioned above, there is one important way in which it is similar to most other government R&D support programs. Defense-related R&D in virtually all OECD economies, especially the much larger procurement programs that typically are linked to these R&D programs, creates strong political constituencies supporting high overall levels of defense R&D spending and continuing expenditures on specific programs with especially significant (and/or narrowly focused) economic benefits.

Another arena where one finds government supported mission oriented R&D programs in many countries is agriculture. In contrast with defense R&D where the government agency funding the R&D usually is the principal user of the results, the principal users of the fruits of publicly funded agricultural R&D are private farmers and industries upstream or downstream from farming. And again in contrast with military R&D, the majority of publicly funded agricultural R&D in most OECD countries is performed in public facilities, either government laboratories or universities.

Brian Wright's chapter focuses on two quite different kinds of programs. In addition to examining the long-established R&D support programs of the U.S. Department of Agriculture, he discusses programs supported by philanthropic foundations that seek to improve agriculture in developing countries.

The principal intended beneficiaries of the U.S. agricultural research support programs are farmers and agricultural processors. The organization and funding of the programs involve considerable decentralization to the states, and the major decisions regarding the allocation of research funding among different kinds of projects are made at that level. Thus farmers at the state level have a considerable amount of influence over what is done. Since farming is a very competitive industry, and the demand for agricultural products at the national and world level is relatively inelastic, the principal actual beneficiaries of agricultural R&D have been consumers. Advances in productivity in agriculture have led both to a significant decline in prices, and to a decline in the farming population. Nonetheless, the principal source of political support for public funding of agricultural R&D remains the agricultural industry.

Wright also describes the genesis and functioning of the programs that have led to the green revolution in wheat and rice production in developing countries. Here, the principal objectives of the foundations funding the work were to relieve and prevent food shortages, as well as supporting higher incomes among farming populations and enhanced political stability in many of the recipient nations.

The research support programs of the U.S. National Institutes of Health are aimed and justified in terms of improving health; the lion's share of the funding goes through Institutes nominally dedicated to particular diseases or other medical problems. While the pharmaceuticals and medical devices industries make extensive use of the results of NIH funded research in orienting their own product development work, the NIH does not justify its programs as a source of commercial benefits for these industries. The NIH conducts a portion of the research it funds in its own laboratories, but the bulk of its research funding goes to universities. In the U.S. the NIH is by far the largest government funder of university research.

Bhaven Sampat's paper describes a continuing struggle between two points of view regarding how NIH funds should be allocated. One viewpoint, often articulated by Members of the U.S. Congress and privately funded "disease lobbies," favors the allocation of a large share of these funds to programs aimed narrowly at identifying and evaluating promising ways of dealing with disease. Another viewpoint, identified with many prominent representatives of the biomedical research community, argues that it is virtually impossible to identify effective preventions and cures unless a disease, and the workings of the human body with which disease interferes, are well understood, and that the NIH should largely fund basic research that has promise of illuminating these matters. In fact, the NIH supports both kinds of work. However, traditionally the NIH has been managed by biomedical scientists who have supported the second of these viewpoints.

The industries that draw on the results of NIH funded research also have favored the use of NIH funds for the support of fundamental research. Their position reflects the fact that they often benefit from this kind of NIH research, as well as industry resistance to NIH programs that may independently develop preventions and cures and thus threaten to undercut the industry's interest in developing and selling its own products for these purposes.

Energy is among the most common areas for publicly funded mission-oriented R&D, and innovation in this field is of central importance in efforts to limit global climate change. The paper by Anadon examines the efforts of the United States, the United Kingdom, and China to support the development and deployment of advanced energy-supply and energy-demand technologies. The goals of these programs in energy R&D are diverse, ranging from climate-change abatement to improved economic competitiveness. Therefore, Laura Anadon argues, instead of "mission-oriented" policies or initiatives, it is more appropriate to talk about their "missions."

Anadon's analysis of energy R&D in three countries that differ greatly in population, political systems and histories of government involvement in the energy sector highlights how variations in national objectives and industrial and political environments translate into variations in policy. Overall, the UK energy programs discussed in the paper are characterized by a number of new programs, each of which has a single goal, as well as considerable involvement of industrial managers in the design of programs. The United States, by contrast, has assigned multiple goals to each of its energy R&D programs, several of which have been based on historical examples of programs or institutions in other sectors widely believed to have been successful in innovation. China's energy R&D programs have undergone little significant restructuring, and state-owned enterprises play a significant role in the implementation or adoption of new technological solutions.

The energy-related R&D programs of these three governments thus differ in the amount of overall coordination among these programs, the extent of involvement of the domestic business community in program design and operations, and the focus of programs on single or multiple missions. Although it is too early to assess the effectiveness of these different approaches to program design, these cross-national contrasts should provide valuable information for future program assessment and evolution.

The papers gathered in this special issue on mission-oriented R&D include both the sectoral studies discussed above and studies of specific policies often associated with mission-oriented programs that focus on technological innovation. The papers on policy instruments in this special issue focus on demand-side policies that have been or are likely to be a part of mission-oriented R&D programs, procurement, regulation, and prizes.

The paper by Charles Edquist and Jon Mikel Zabala-Iturriagagoitia discusses the role of public procurement in innovation programs seeking to address societal needs. The authors examine six cases of public procurement, differentiating them along three dimensions: (i) the user of the purchased good; (ii) the character of the procurement process; and (iii) the cooperative or non-cooperative nature of the process. In some of the cases examined in the paper, the public agency procuring the innovative technology or product is not the final user, but in others (e.g., defense) the product is intended for use by the public-agency customer. The cases examined in the paper also differ in the structure of the procurement process, as the authors conclude that procurement is likely to be more effective when broad functional (e.g., performance) specifications form the basis for assessing success in meeting requirements, in contrast to the use of detailed technical specifications. But reliance on functional specifications also requires a deep understanding of both technological constraints and the application environment for the technology or product.

Another tension in the structure of procurement policy is that between policies that support the kinds of learning-rich interactions in "cooperative" procurement transactions and policies that support vigorous competition among potential suppliers. The authors conclude that public procurement is a potentially powerful instrument for the support of mission-oriented R&D programs, although it is likely to be most effective when used by governments in combination with other instruments (e.g., R&D investment or incentives for private R&D investment) to promote innovation in a specific field.

As we noted earlier, few if any of the societal challenges cited earlier are likely to be overcome without enlisting the private innovation capacities and the entrepreneurial dynamism that decentralized market economies can mobilize. The centrality of private innovation capacities is particularly true in the case of climate change. This is the main argument developed in the paper of Reinhilde Veugelers: the "private innovation machine" cannot be expected to be socially effective on its own, because of the combination of negative environmental externalities and knowledge spillovers. As a result, public policy needs to be designed as a portfolio of instruments including carbon prices, and regulations. Technology policy thus should include demand-side instruments to accelerate the adoption of new technologies in addition to supporting R&D and knowledge generation.

Veugelers examines the evidence on the effectiveness of environmental regulatory policies that seek to encourage private-sector investment in developing and adopting clean technologies. As she points out in her paper, the econometric evidence on this question is sparse and does not clarify what instruments and policy designs are most effective in influencing private initiatives and commitments. A key contribution of the paper is its discussion of new evidence drawn from the Flemish CIS (Community Innovation Survey) eco-innovation module. The evidence discussed here supports the importance of combining regulation and taxes with a vigorous technology policy in order to accelerate the adoption of CO_2-reducing innovations. The limited evidence highlights the complementarity among the various instruments and the author concludes that any R&D subsidy, if distributed in a context of great uncertainty about the future evolution of carbon price, is likely to have little if any positive effect on private incentives for the adoption of new technologies.

Although they have been employed by governments in the past (see Sobel, 1995), Grand Innovation Prizes (GIPs) recently have been promoted by policymakers and analysts as a new instrument to be added to the toolkit of mission-oriented policies. The paper by Fiona Murray, Scott Stern, Georgina Campbell, and Alan MacCormack examines GIPs, which are defined as large monetary prizes awarded to the innovator(s) that provide the first or best solution to a predefined technological challenge. Theorists have cited several potential advantages of GIPs as innovation policy instruments. They address the market failure caused by the existence of knowledge externalities while not necessarily granting exclusive rights for the innovation to the prizewinner. Properly structured prize competitions also can attract entry by innovators, firms, and other entities that might be discouraged from entering procurement competitions sponsored by public agencies, and thereby have the potential to support the development of more novel technical solutions.

Prize competitions provide the policy maker with a mechanism to induce private investment in development of specific technological advances that shares some features with the procurement policies described by Edquist and Zabala-Iturriagagoitia. And under certain conditions, prize competitions may have advantages over procurement policies for such goals. An open prize competition may attract a more diverse range of competitors than would be involved in a typical procurement competition. The often substantial burden of monitoring competitor performance that is a central feature of procurement competitions may be less onerous in prize competitions. These and other advantages for prize competitions that are advanced by advocates of prizes, however, rest on a range of assumptions about the structure and operation of prize competitions in practice.

The paper by Murray et al. draws on a detailed case study and other evidence to provide a useful corrective to the idealized representation of GIPs. They develop an evaluation framework, involving three dimensions – objectives, design and performance – and offer an empirical evaluation based on a study of the Progressive Insurance Automotive X Prize which aimed to induce the design and development of radical new designs of highly fuel-efficient automobiles. The authors find that the empirical facts about competition objectives, design and performance depart from the depiction of the advantages of prize competitions that is presented in much of the economics literature on this topic. For example, many contemporary prize contests grant exclusive rights to competition winners through allowing them to patent the results. Moreover, Murray et al. note that in the case of the Automotive X Prize, the specification of the criteria determining the winner was a complex process that revised these criteria on several occasions. The paper concludes that a GIP is not a 'simple' or an 'easy' tool to encourage innovation in a specific domain, but involves complex issues of management, coordination and evaluation.

3. Guidelines for policy design[2]

We believe that there are some general lessons that can be drawn from the experience with mission oriented programs and policy instruments discussed in these papers. Mission-oriented R&D programs for future societal challenges must support the development and deployment of many different technologies that will be employed in a diverse array of sectors throughout the world. Such public programs should focus on long-term support for the development and improvement of relevant technologies, rather than seeking a one-time technological breakthrough.

The importance of rapid and widespread adoption of technological solutions to these challenges highlights the role of public policies affecting demand for these technologies. Successful mission-oriented R&D programs often have benefited from strong demand by potential users for the technologies developed by these programs. In at least some of these programs, public policies directly or indirectly supported the demand for the new technologies.

Government is likely to be an important user of some of the new technologies developed for addressing climate change or global public health, and public procurement or regulatory policies can be used to promote certain technologies or applications.

Another challenge for the design of mission-oriented R&D programs in these and other societal challenges is the development of criteria and processes for identifying where and how public investments can catalyze, complement, and usefully augment private-sector investment in R&D. One guideline for public support for R&D in industry and elsewhere is that such funding is appropriate for projects in which the value to society of the expected returns to R&D is high but private firms' willingness to invest at that stage is low. An important class of such work focuses on the creation of new knowledge and techniques that are at some distance from commercial application but that are nevertheless important to future problem solving and design. Such projects include many types of basic research, where the nature and range of potential applications is uncertain and the ability of private investors to capture the returns is likely to be limited even if the research is successful.

This type of R&D also includes research focused on overcoming specific roadblocks to the development of new or improved technologies, where the success of particular efforts is highly uncertain. Work of this type also may involve the design, development, and testing of prototypes of new technologies, particularly when the results of such prototype tests are placed in the public domain. Much of the mission-oriented R&D in agriculture, energy and the biomedical fields described in this special issue included such projects, which focused on solving practical problems where the social returns to such solutions were high and the private returns were low.

The social returns to R&D that yields results of wide applicability are likely to be greater when those results are broadly available than when they are restricted. For this reason, it is important that governments structure their R&D programs to support and encourage broad dissemination of the scientific and technological knowledge produced by their R&D investments in the relevant fields. We believe that patenting should be reserved for results that are close to practical application and that patenting of research results whose use is primarily as an input to further research should be minimized. Moreover, licenses to these patents generally should be available to all parties, conditional on paying reasonable royalties.

The U.S. Defense Department's R&D programs, along with U.S. competition policy, supported the development of a relatively "open" industry-wide knowledge base in the early semiconductor industry, accelerating firm entry and innovation. In a similar vein, funding of the Human Genome program by NIH, MRC, the Wellcome Trust and others helped keep an important new knowledge base open and available to a wide range of firms who sought to make use of it. By supporting work to create lines of seeds that bred constant and true, and making these seed lines broadly available to seed companies, the U.S. Department of Agriculture supported entry into the nascent hybrid seed industry. In all of these areas,

[2] This section draws on Mowery et al. (2010).

the support provided by public mission-oriented R&D programs for the broad dissemination of fundamental knowledge neither discouraged industry R&D investment nor does it appear to have discouraged privately funded innovation.

It is also important that public funds do not enable industrial performers of such R&D to establish monopoly positions in important technological fields. More generally, it is essential to maintain a "pro-dissemination" posture toward this type of R&D. Where public funds support R&D performed by industry, wide dissemination of and access to results generated by others should be supported by policy.

As a technology advances, a transition from research to development and commercialization will occur, and this transition will be reflected in a shift from public to private funding. The timing of these transitions will be specific to individual technologies and uncertain, making it difficult if not impossible to plan or predict the structure of the overall R&D effort in any detail, a characteristic that can be frustrating to those responsible for monitoring the overall effort. Yet this complexity is a strength rather than a weakness. Solutions to current societal challenges, as we have pointed out above, will involve many different technological advances, and in many areas the most promising paths toward those advances are highly uncertain. Such pervasive uncertainty means that public R&D programs must encourage diversity and competition in R&D, as well as in the industries that will be developing and using the new technologies.

It is important that public R&D programs maintain good communications with users of the technologies that the programs seek to help develop or improve, and that program managers have a good understanding of user needs. At the same time, user interests should not be allowed to dominate program design, management, and priorities; the example of agricultural research in the United States illustrates the possibility of "capture" of public R&D programs by powerful user groups. When established firms or user groups are able to exert a dominant influence over the agenda of public R&D programs (which is particularly likely in public–private consortia enlisting established firms within an industry), these programs are likely to focus on near-term improvements in existing technologies. Public funding for marginal improvements of existing technologies is almost certainly less important than support should for advancing the technological frontiers.

Research and development obviously are central activities in innovation and the improvement of established technologies. Learning in use, however, is another important source of advance in these technologies, and this form of learning will be especially important for decades to come in mission-oriented R&D programs that seek to promote the adoption as well as the development of technological solutions. Complex new technological systems of the sort likely to be developed for these purposes typically undergo prolonged processes of incremental improvement that over time produce dramatic advances in overall performance, reliability, and cost-effectiveness. The knowledge resulting from this learning needs to be disseminated among prospective users and should feed back into the R&D processes that promote additional modifications and improvements in these technologies.

Although we argued earlier that public R&D support should focus on significant new technological opportunities, another appropriate role for public funding in mission-oriented programs is selective support of demonstration projects. Demonstration projects provide a bridge between R&D and use of a technology in the environment of actual practice. They can provide information to potential users or developers about a given technology's performance in actual practice, and may highlight the features of a given technology that are most in need of improvement for commercial success. As such, demonstration projects can guide future R&D investment by public- and private-sector actors.

There are a number of examples of demonstration projects in the government R&D programs discussed earlier in this paper. An important component of the agricultural research programs in the U.S. and the U.K. is field trials of new methods, which provided valuable information to farmers and guidance to technology developers regarding further research. Government biomedical R&D programs in both the U.S. and the U.K. have supported clinical trials of new medical practices. Much of the prototype development associated with the military procurement programs that contributed to technological development of the aerospace and IT industries in the United States similarly served to demonstrate the feasibility of new design concepts and applications. Although U.S. energy demonstration projects have not enjoyed comparable success, we believe that effective public programs to support the development of alternative energy technologies should also include mechanisms for the support and encouragement of early trial use of new technologies so that their promise can be evaluated and the necessary improvements identified.

Another important issue of program design concerns the balance between decentralization and centralization in program structure and governance. A considerable amount of decentralization is desirable or even essential in an energy R&D program that spans such a diverse array of technologies, industries, countries, users, and applications, and which involves such a wide range of activities. Nonetheless, a centralized administrative structure for setting broad priorities, monitoring overall progress, and evaluating performance is a necessary complement to a decentralized program structure. The needed coordination mechanisms will therefore have to operate effectively among as well as within agencies.

Whatever the particular organization of the program, it is important that its broad orientation and funding be stable and credible. As the paper by Anadon points out, a crucial weakness of U.S. energy R&D policy historically has been the instability of program goals and funding. The effects of such instability are detrimental not only to the public programs involved. In a field such as energy, large-scale private investments in R&D and technology deployment are essential, yet are discouraged by perceptions that funding and other policy commitments are fleeting rather than sustained and credible. Stability and credibility are therefore important goals for the design of mission-oriented R&D programs across the board, and are essential as in demand-side policies that create incentives (and disincentives) for private-sector investors in R&D and technology deployment.

Finally, an element of program design on which the discussion in these papers of mission-oriented R&D programs provides limited guidance is the need for programs seeking solutions to global problems to be structured to the global scope of these problems. Combating global warming, for example, requires that technological solutions be deployed on a global scale as soon as possible. Moreover, the global nature of technological solutions means that the institutional, economic, and/or industrial settings within which these solutions are deployed will be enormously diverse, requiring a great deal of "localized" adaptation of these solutions.

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