SCIENCE POLICY IN ITS SOCIAL CONTEXT

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Public support of science is justified by three primary instrumental rationales: scientific advance is necessary to create new wealth; scientific advance is necessary to solve particular societal problems; and scientific advance provides the information necessary for making effective decisions. Significant and persistent disparities between promise and performance accompany each of these rationales.

Our argument is that these disparities in part reflect science policy decisions made without adequate consideration of broader social contexts. To explain this point, we present an illustrative example for each rationale. We then discuss some approaches to more effective contextualization of science policy decisions. Such approaches could improve the capacity of science policy to achieve desired social outcomes, and reduce the potential for/and magnitude of negative outcomes. Failing this, they could at least create more realistic expectations and understandings of the roles, and limits, of science in society.

What Science Policy Is

Science policy is the decision process through which individuals and institutions allocate and organize the intellectual and fiscal resources that enable the conduct of scientific research. The proximate consequence of science policy in the U.S. federal government is the $118 billion that was spent in 2003 on the publicly funded research and development (R&D) enterprise (AAAS, 2004). On a global basis, government science policy decisions are responsible for the allocation of perhaps three times this amount (OECD, 2003). Through these expenditures, science policy decisions are a powerful catalyst for social and economic change.

Science policy in the United States federal government is carried out at many levels and in many organizations, ranging from the Office of Management and Budget in the White House, to managers of individual programs in federal agencies, to members of Congress who sit on relevant committees. Participants in the policy process include not just elected officials and bureaucrats, but scientists and a broad range of citizen stakeholders. There is, therefore, no unified science policy process, but it is conceptually useful to think about a science policy as the aggregate of the decisions that are made in these many policy venues.

Public funding for science is justified primarily on the basis of anticipated and specified societal benefits. The foundational case, and America's most important science policy document, is Vannevar Bush's *Science—the Endless Frontier* (1945), which stated, for example, that "advances in science will also bring higher standards of living, will lead to the prevention or cure of diseases, will promote conservation of our limited national resources, and will assure means of defense against aggression" (9).

Bush's compelling rhetoric helped set the stage in subsequent decades for the avalanche of promises made on behalf of public science by a variety of government agencies and science advocacy groups. Promotion of "basic" research focuses on expanding the reservoir of knowledge as a basis for solving a broad range of problems. "Directed" basic and applied research are justified for their potential to solve particular problems. But in all cases, it is the promise of concrete social benefits that rationalizes the demand for public support of science, and motivates science policy making. For example, a May 2004 advertisement in the *Washington Post* advocating more federal support for undirected, basic research nonetheless connects such research to specific, beneficial applications: "Research in Basic Science Brings Innovations that Improve our Lives . . . Like Solar Energy" (University Research Association, Inc., 2004). The unstated assumption in such assertions is that the societal benefits of science are inherent in the science itself. Indeed, the idea that social benefit resides in science is the foundation of modern science policy dogma.

Scientific advance, however, is usually accompanied by a range of societal outcomes. For example, science-based technological innovation, offered as the key to economic growth in modern society, is also implicated in increased concentration of global wealth and gradual but progressive disenfranchisement of the manufacturing workforce. In the United States, a recent manifestation of this disenfranchisement is the so-called "jobless recovery" where measurable outputs have increased on a per-worker basis, without concomitant increases in employment.

This range of outcomes might be most apparent in medicine. Biomedical research is funded at robust and rapidly increasing levels because of the expectation that it will cure some diseases and prevent others. Meanwhile, infectious diseases are resurgent throughout the world, and the rising costs of health care in affluent countries are fast outstripping the capability of society to pay for them. In the area of the environment, billions are spent each year on research aimed at reducing uncertainties and clarifying political options for addressing the challenge of global climate change, yet a political solution to the problem remains out of reach, and climate impacts continue to mount.

Our point is certainly not that science is the "cause" of such complex and often paradoxical outcomes, but that science is only one among many intertwined causes. Historically, this complex and attenuated coupling between the conduct of science and the outcomes of science in society has been the foundation of a central claim of science policy—that neither the course of science, which begins with the unfettered exploration of fundamental phenomena of nature, nor its use and outcomes in society, can be predicted in detail and far in advance (e.g., Bush, 1945; Committee on Science, Engineering, and Public Policy, 1993; House Committee on Science, 1998).

This claim is accompanied by another, more subtle but omnipresent one: that benefits flow more or less automatically and inevitably from research, and are thus inherent in the process of knowledge production itself. Undesirable outcomes are the consequences of factors extrinsic to the science. Together these two claims justify science policies that focus on ensuring the health of an autonomous scientific enterprise as measured by criteria internal to that enterprise, such as levels of funding, production of papers, patents, Ph.Ds and Nobel prizes, and the operation of quality control mechanisms, such as peer review, that assure the health and effectiveness of, in Michael Polanyi's memorable term, "The Republic of Science" (Polanyi, 1962; see also Weinberg, 1963; Panel on Scientific Responsibility, 1992). The internal health of the enterprise guarantees the external benefits to society. The metrics of health include *outputs* (e.g., patents, publications), but not *outcomes* (Sarewitz, 1996).

Economists of science and technology have made modest strides in evaluating the economic rate of return on public investments in science, which apparently are significant (e.g., Griliches, 1995) but such work inevitably reinforces the tendency toward understanding science only in terms of its benefits. Analysis and tools that seek to understand and assess the connections between science policy decisions and non-economic social outcomes are virtually absent from both science policy scholarship and practice. Science policy dogma renders such efforts both impossible (due to the unpredictability of outcomes) and unnecessary (due to the automatic nature of benefits).

If, however, the outcomes of science are determined or co-determined by factors extrinsic to science, then no defensible claim can be made about putative benefits (or, for that matter, detrimental effects) based solely on the attributes of the research and the internal operations of the science enterprise. Science is *always* applied within a broader problem context. Put somewhat differently, when it comes to social problems, science cannot *solve* anything; science works within a broader set of social, cultural, political, and economic conditions in contributing to solutions and problems. While scholarship in the area of science and technology studies has documented from many perspectives this contextual embeddedness of science (e.g., Jasanoff et al., 1995), the question of what this embeddedness implies for the relations between science policy decisions and specific social outcomes has been generally neglected (but see, e.g., Lyall et al., 2004; and Bozeman and Sarewitz, in press).

Any claim that science will lead to a particular social outcome—positive or negative—should be viewed with suspicion. But most science policies are justified solely on the claim of benefit, are advocated largely in terms of the resource needs of the research enterprise, and are advanced with little consideration of broad social context. Given the complex linkages between research inputs and social outcomes, such policies should not be expected to fulfill specific promises, and should be expected to yield unexpected and contradictory outcomes.

To more fully explain our argument, we now briefly discuss complex outcomes associated with the three primary instrumental rationales of science policy: creating wealth; solving societal problems; and providing information for decision making. We focus, respectively, on the examples of wealth distribution, health outcomes in developing nations, and global climate change.

Science and the Creation of Wealth: Innovation and Inequality

If there is a core premise for national investments in science, it is the promise of widely distributed economic benefit. Wrote Vannevar Bush:

> One of our hopes is that after [World War II] there will be full employment. . . . To create more jobs we must make new and better and cheaper products. We want plenty of new, vigorous enterprises. But new products and processes are not born full-grown. They are founded on new principles and new conceptions which in turn result from basic scientific research. (1945, 6)

Consider, for instance, the case of nanoscience and nanotechnology, a new research area that has attracted hundreds of millions of dollars in public investment. The development of nanotechnology is supposed to allow industry to create limitless supplies of products with reduced costs, ending the dependency on traditional raw materials and limiting environmental impact. Moreover, nanotechnology is considered the core of the next industrial revolution in both the post-industrial and the industrializing worlds (Interagency Working Group, 1999; Mantel, 2003; Garcia, 2004).

The idea of economic growth as a direct consequence of investments in basic science (via technological innovation based on that science) became dominant after WWII. During the 1980s, however, the relationship between science, innovation and economic performance started to be analyzed through more complex, nonlinear approaches inspired by economist Joseph Schumpeter´s theory of innovation (Dosi et al., 1988; Nelson, 1993; and Freeman and Soete, 1997). From this perspective, the economic performance of nations can be understood in terms of national "innovation systems," and the creation and use of new knowledge can be recognized as the fuel for such systems (Mowery and Rosenberg, 1993; Odigari and Oto, 1993; Nelson, 2000; Kim, 2001; Gabriele, 2003). These connections justify a general commitment to publicly funded science, especially science that, however "basic," has some potential link to innovation and technology development (House Committee on Science, 1998; and Stokes, 1997).

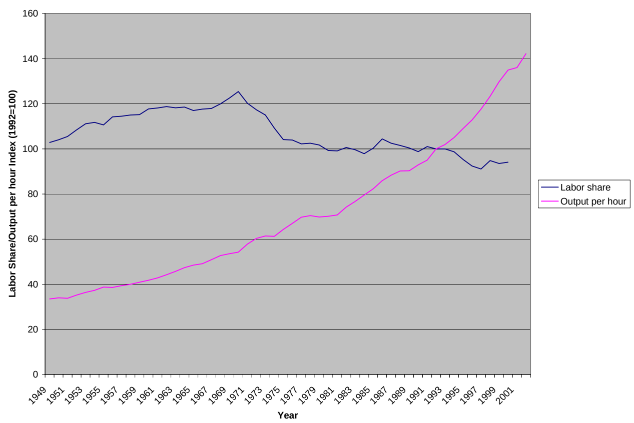
However, the experience of the past 30 or more years shows that the phenomenon of science-and-technology-based economic growth seems to be accompanied by increasing inequality in distribution of economic benefits (Noble, 1995; Lesinger, 2002; Arocena and Senker, 2003; and World Bank, 2004). This inequality appears on numerous fronts, including high unemployment and underemployment rates, persistent levels of poverty, and soaring concentration of wealth, each of which are apparent both within nations and between nations on a global basis, even as global wealth continues to grow (Sen, 1997; Castells, 2000; US Census, 2000; Wade, 2001; inequality.org, 2003; and ILO, 2004).

The current employment situation, for example, stands in striking contrast with the promises of a better quality of life that investment in science and innovation would allow. The ILO estimates 185.9 million unemployed worldwide in 2003, the highest level ever recorded (ILO, 2004, 9). Although the situation is especially bad in less developed countries, all highly industrialized nations have experienced high unemployment rates since the 1970s.

The causes of unemployment are complex and multifaceted, and certainly include economic slowdown and population increase. The connections between unemployment and science-and-technology-based innovation is a particularly controversial issue (Kaplinsky, 1987; Mattoso, 2000; and Hatch and Clinton, 2000), but increases in productivity brought about by new technologies and new production practices is a central attribute of innovation and wealth creation (Figure 1). In the U.S., an obvious consequence in some manufacturing sectors, such as textiles, apparel, and heavy machinery, has been absolute reduction of employment (Hatch and Clinton, 2000). Even new and dynamic industries such as information and communication technology, which had been creating new jobs during the 1980s and 1990s, are expected to demand fewer jobs in the first decade of the 2000s, according to U.S. Bureau of Labor Statistics employment projections (BLS, 2004). Significant shifts in the character of employment is part of the same process, with lower-skilled jobs in the high-paying manufacturing sector giving way to lower-paying service sector jobs (USDOL, 2003; American Prospect 2003; and Bellamy Foster et al., 2004). In developing countries such as those of Latin America, industry efforts to adapt to new production and competitiveness conditions during the last twenty years have also had adverse consequences on employment (Katz, 2001; Delgado Wise and Invernizzi, 2002; and Invernizzi, 2004).

The global proliferation of scientific and technological capacity has not been sufficient to quell the growth of economic inequality. Indeed, at the global scale, rising concentration of national wealth has been a central element of economic development for 300 years, correlating strongly with concentration of technical capacity. Between 1960 and the end of the 1990s, the income gap between the top and bottom twenty percent of world population more than doubled, increasing from 30:1 to 74:1 (Leisenger, 2002).

Figure 1. Share of Work and Output per Hour in the United States Manufacturing: 1949-2001 (Index 1992=100).



Source: US Department of Labor.

Science and technology policy are obviously not themselves directly responsible for rising inequality or unemployment—but neither are they directly responsible for economic growth. Needless to say, public investments in science and technology are justified on the basis of promised growth, not on the basis of anticipated future increases in unemployment and wealth disparity—although employers have often adopted new technologies with the explicit intent of reducing the number of their employees (e.g., Noble, 1986). Our point is that while such outcomes have been accompanying the advance of knowledge and innovation, science policy decision processes have consistently failed to consider their implications. Innovation policy continues to focus on innovation per se, considering it as an inherently and exclusively positive contributor to economic and social development, and failing to consider the implications of persistent, adverse social outcomes for policy design.

Science and Problem-Solving: Medical Research and Global Health

The moral crisis created by inequitable access to AIDS drugs is perhaps the archetypal example of how the promise of science interacts with the real world to create complex outcomes. More than 90 percent of AIDS sufferers worldwide cannot afford the life-saving treatments available to patients in affluent countries (UNAIDS/WHO, 2002).

The problem partly reflects how R&D activities are partitioned in society, with fundamental research typically supported by public funds and applied research and development increasingly the responsibility of the private sector (Kettler & Towse, 2001). Because corporations must recover their R&D investments and reward their stockholders, they focus on problems with high potential returns, charge what the market will bear for products, and often protect them with patents. They also develop products appropriate to the healthcare infrastructure of high-tech societies (MSF/DND, 2001).

Efforts to broaden access to AIDS drugs have focused on offering generic products at reduced prices to poor countries, especially in Africa (MSF, 2003; and Vedantam, 2004). In other cases, notably Brazil, in-country generic drug production in violation of intellectual property regimes has been chosen to increase distributional equity. Under political pressure, large pharmaceutical corporations have agreed to lower prices in Third World Countries such as Brazil (Bermudez et al., 2002).

We note, however, that these reactions come fifteen years after major public research investments were first stimulated by the rapid increase in AIDS incidence worldwide, and that they are unlikely to save the lives of most AIDS sufferers in the world today. Could different science policies have led to better outcomes?

Public-private partnerships (PPPs) in biomedical research have recently emerged as a new mechanism for funding science aimed at the health problems of developing countries. PPPs are non-profit organizations whose participants may include pharmaceutical companies, national and international public institutions, charitable foundations, and other nongovernmental organizations interested in global public health. Donations from foundations, governments, and international organizations subsidize the scientific capabilities of corporations to address problems that the private sector would otherwise ignore, such as drugs and vaccines for tropical diseases. PPPs also allow greater flexibility in pricing and distribution policies for research products. Over ninety-one health PPPs are now in operation, including the International AIDS Vaccine Initiative, Roll Back Malaria, and the Global Alliance for Vaccines and Immunizations (Foladori, 2003a; and 2003b).

PPPs, in other words, are a science policy innovation aimed at pushing R&D in directions it would not go using more conventional policy approaches. They respond to a global context in which the promise of biomedical science can only be redeemed by a small percentage of people in the world. Yet PPPs only internalize one element of that context—lack of market incentives in small underdeveloped countries. Pharmaceutical corporations will not allow large developing markets such as China, Brazil or India to benefit from the partnerships. They still reflect an approach to science and technology that treats research products as the functional equivalent of problem solutions. They do not address the underlying causes of disease in the developing world, nor do they necessarily separate themselves from the interests of the pharmaceutical industry.

Even in the case of preventive efforts, such as R&D on vaccines, PPPs are interested in new vaccines (e.g., Hepatitis B), while continuing to neglect immunization against diseases for which vaccines have existed for years (LSHTM, et al., 2002; and Hardon, 2001). This trend is encouraged because PPPs generally hold patents on the products they produce and can thus create self-sustaining revenue by inventing new products. Similarly, participating pharmaceutical companies may gain tax benefits, opportunities to create and open new markets, information and results from other companies collaborating in the PPP, and additional support for R&D from the PPP (Kettler and White, 2003). In total, the PPPs and the collaborating corporations benefit more from inventing new vaccines than from disseminating old ones. Moreover, the use of patents as an incentive for corporations to participate in PPPs privatizes biomedical research results that are paid for with non-private funds, and thus may reduce public access to knowledge that should arguably be a public good. Even in cases where PPPs are not seeking patents, they are still abiding by international patent agreements that limit the conditions under which generic drugs can be sold in developing countries, and thus limit access of poor people to existing treatments. Table 1 summarizes various arguments for and against PPPs.

The historical relationship between disease and development shows that the direction of causation typically runs from economic development and equity to improved health, and not the other way around. The decline of most major infectious diseases in western countries coincides with improvements in infrastructure and standard of living. Effective medical interventions have usually arrived after disease incidences were already on the decline (Dublin, 1948; McKeown, 1988; and Delarue, 1980). Conversely, major improvements in life expectancy in many of the poorest countries in the world have not translated into commensurate increases in standard of living.

These complex relations suggest that PPPs will neither be able to reverse the growing public health crisis in many developing countries, nor catalyze economic growth: extreme inequities in wealth distribution in many developing countries are likely to keep people mired in both poverty and disease. This relationship is vividly illustrated by the work of anthropologist Peter Brown (1987), who tested the hypothesis that malaria was blocking economic development on the island of Sardinia in the period after World War II. He concluded that the "macroparasitism" of landowners drained thirty percent of the production capacity from peasants in the form of rents, while the "microparasitism" of malaria accounted for less than ten percent reduction in their gross production. The effects of social relations were at least three times greater than the effects of the disease.

Finally, PPPs reflect a charity-based model of development aid that does not foster increased technological capacity among developing countries. PPPs may successfully develop drugs and vaccines that can save lives. But they are unlikely to materially improve the lot of the poorest nations. Under typical conditions suffered by communities in poverty, even if a disease is eliminated, a new one is likely to take its place (Evans et al., 1991). Science policies designed without awareness of this context are unlikely to fulfill their promise.

Science and Decision Making: The Impacts of Climate Change

Global climate change has emerged over the past several decades as a galvanizing environmental issue that presents enormous challenges for decision makers across a variety of societal activities ranging from agriculture and energy to public health and safety. Given the complexities and uncertainties involved, decision makers have turned to science to provide information that can guide effective action, and most research has focused on understanding the dynamics of climate behavior and characterizing the causes and future of climate change. Policy debate, in turn, has focused on the problem of mitigating potential human disruption of the climate system, especially through reduced emissions of greenhouse gases.

The foundational science policy claim here is that research on climate will enable better decisions through enhanced understanding of climate function and reduced uncertainty about future climate behavior (e.g., Climate Change Science Program, 2003). The idea, of course, is that scientific understanding of climate change is the appropriate basis for effective action, because action must be rooted, first and foremost, in a factual understanding of the world. This idea is further rooted in the belief that such appropriate action can lead to the control of future climate behavior, and through such control, the reduction of adverse climate impacts on society. This line of argument has

Item	Argument in Favor of PPPs	Concerns	Authors
R&D Orientation	PPPs could deal with neglected diseses for less developed countries. For the public sector it will be more costly and inefficent to develop skills on F&D that pharmaceutical corporations (pharma) already have.	Pharma will only particpate on new drugs or vaccines that would be patented. Old infectious diseases without patents could reemerge. Benefits will only reach less developed countries with no market. Pharma will not permit low prices to reach important markets such as India, Brazil, or China. Poor people from developed countries will not be considered. Public R&D had hsitorically been capable of producing vaccines and new drugs (polio, cancer, meningitis), or replicating others (AIDS).	Evans, 2001 Hardon, 2001 Orbinski, 2001 Hancock, 1998
Reduce Risk & Increase Resources Sustainability	PPPs could lower the risk of R&D. The World Health Organization (WHO) needs to increase its budget and PPPs raises funds.	Nobody is accountable for PPPs outcomes. Shareholders do not participate in decisions. Some studies show an increase in costs of PPPs. There are other ways than philanthropy to deal with R&D, such as taxation, public production and distribution. R&D on drugs and vaccines need a long term budget. It is doubtful if PPPs could be sustained by donations; still push & pull mechanisms will be needed. The WHO splits world health policies into several PPPs, which raises doubts about efficiency.	Pollock *et al*, 2002 Kettler & Towse, 2001 Lob-Levyt, 2001 Orbinski, 2001 Walt, 2000 Hancock, 1998 Muraskin, 2002
Mutual Confidence Between U.N. and Corporations	PPPs represent the way to address health problems	History shows corporations have used the U.N. for private interests. The U.N can not monitor corporate responsibility. There is a hidden agenda for corporations: political influence, set the global public agenda, enhance legitimacy, promote image, market penetration.	Boseley, 2003 Ollila, 2003 Richter, 2003 Dukes, 2002 Yamey, 2002 Buse & Waxman, 2001 Hancock, 1998
Is There an Alternative to PPPs?	PPPs represent the way to address health problems	PPPs will only deal with diseases of pharma interests. 1/4 of PPPs are for AIDS and for less developed countries. There are alternatives: public R&D and delivery of medicine and vaccines.	Ollila, 2003 Richter, 2003 Muraskin, 2002 Vakhovskiy, 2001 Hancock, 1998

Table 1

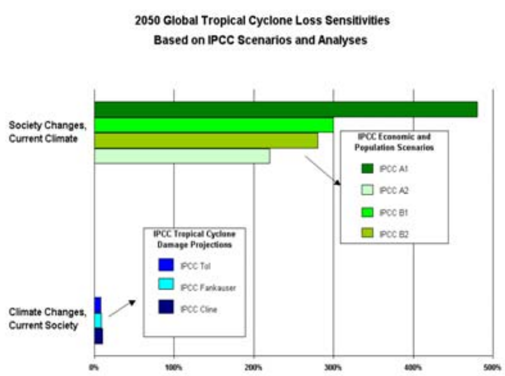
thus far justified on the order of twenty billion dollars of research in the U.S. alone. However, it is fair to say that, beyond the intense diplomatic and political activity surrounding the negotiation of the Kyoto Protocol and related treaties, little progress has been made toward reducing greenhouse gas emissions. More importantly, this path has led to virtually no progress on reducing the negative impacts of climate on society.

For example, the prospect of climate change stimulates the concern that changing weather and climate patterns will result in greater disruption to society, especially in the developing world (e.g., McCarthy et al., 2001). In this context, consider the catastrophic consequences of Hurricane Mitch in 1999, which included more than 10,000 deaths in Nicaragua and Honduras, as well as the virtual destruction of those nations' economies and a subsequent cholera outbreak (Alvarez et al., 2001). As a weather phenomenon, hurricane Mitch was not unprecedented. Its dire consequences were due to the vulnerability of the impoverished societies that lay in its path, with their dense populations, poor infrastructure, unregulated development, rampant environmental degradation, and ineffective disaster response capabilities. No amount of understanding of the future of climate behavior can change those causal factors. Indeed, the current state-of-the-science suggests that, in the coming decades, demographic and socioeconomic changes are likely to be twenty to sixty times more important in contributing to economic losses from hurricanes and typhoons than climate change (Figure 2; and Pielke et al., 2000).

perate climates. Yet given the well-documented socioeconomic origins of most severe infectious diseases, not to mention the fact that such diseases already affect millions throughout the world, it seems implausible that reducing climate change could be an efficient path to controlling infectious disease. Overall, reducing the human influence on climate behavior is an extremely indirect way to confront the many problems that are often attributed to climate change. Moreover, given the complexities of both climate and society, it will never be possible to determine how changes in, say, greenhouse gas emissions translate, via changing climate behavior, into beneficial social impacts.

This is not to argue against emissions reductions. Certainly it would be wise to minimize the potential for human-induced changes in climate behavior. But the logic that underlies climate science policy asserts a causal chain that is implausible: from scientific understanding on climate, to appropriate action (that overcomes entrenched vested interests) on emissions reduction, to beneficial consequences in terms of controlling climate impacts. Meanwhile, since the 1970s, U.S. public and private investment in energy R&D has declined by almost two-thirds, in real dollars (Energy Research Agency, 2001). This is an incredible counterpoint to the billions spent on climate change research, and is *prima facia* evidence for the failure, even on its own terms, of cli-

Figure 2. Comparison of Tropical Cyclone Loss Estimates from Socioeconomic Changes (Top Four Bars) and Climate Changes (Bottom Three Bars). Source: Pielke et al. (2000).



Similar arguments apply to other anticipated areas of climate change impact. For example, climate change may influence patterns of precipitation and evaporation, but population growth and other sources of growing water consumption appear to be much more significant drivers of water resource depletion than global warming (e.g., Vorosmarty et al., 2000). In the arena of public health, climate change is suggested as a possible cause for the spread of normally tropical diseases into temmate science policy. This failure strongly reflects the power, and danger, of a science policy dogma that asserts that more scientific understanding must lead to more societal benefit, and thus allows problems rooted in socioeconomics and politics to be redefined as agendas for scientific research.

Toward a Contextual Foundation for Science Policy

Any claim that a particular scientific research or technology development program will lead to a particular social outcome reduces a complex social problem to a science policy problem. Science and technology cannot correctly be thought of as the starting point of a causal chain leading to a particular specified social outcome; rather, they must be understood as elements of a complex context from which outcomes emerge.

If this is correct, then conventional rationales for science policy as a process of allocating resources for the creation of knowledge and innovation make no sense. Either the claim that particular science investments will lead to particular social benefits must be abandoned as incoherent, or science policy decision making in general must be informed by a much deeper understanding of the contexts within which social problems develop and can be confronted. The first alternative is not politically viable because to give up on the claim of particular benefits would assuredly undermine the claim to the public resources upon which science depends. The second alternative seems to demand an analytical breadth that real world policy making is unlikely to be able to achieve and from which it is unlikely to be able to benefit.

A third possibility would be to extend the notion of science policy itself to give equal weight to the processes of knowledge creation and use. The theoretical basis for this reconceptualization is by now well-established, and rests on two ideas: first, that ongoing communication between the producers and users of knowledge and technology can help create more concordance between what research produces and what users need; and second, that the outcomes of new knowledge or technology strongly reflect the capacities of those who are using them. Scholarship in the economics of innovation and the social dynamics of science has greatly expanded understanding of scientific research as a socially embedded process, and of the products of research as therefore coproduced by science and society (e.g., Jasanoff, 1996; and Wynne, 1991). Case-based studies of technological innovation show pervasive and continual feedbacks among knowledge creation, technological evolution, political decision-making, and the marketplace (e.g., Leslie, 1993; Rosenberg, 1994; and Nelson, 2000). Broadening the constituencies who participate in science policy decisions has been offered by scholars as one way of better connecting decisions about research to desired outcomes (e.g., Funtowicz and Ravetz, 1992). Examples from areas of research as diverse as biomedicine, agriculture, computer technologies, and natural hazards show that formal and informal participatory processes can increase mutual understanding among scientists and the potential users of the products of science, influencing research paths and product development in ways that better meet user needs (e.g., Epstein, 1996; von Hippel, 1988; Cash, 2000; and Sarewitz et al., 2000).

Demanding equal status for knowledge creation and knowledge use in science policy turns the standard policy dogma on its head in two related ways. First, it recognizes that the trajectories of knowledge creation are not given by nature itself, or revealed through unfettered scientific inquiry, but rather are a consequence of many influences, some internal to, and others external to, the formal scientific research enterprise (e.g., Kitcher, 2001). Second, it locates the value and utility of scientific research in those who can make use of its results, rather than in the results themselves.

These two insights can be operationalized in science policy by means of a fairly simple conceptual innovation. The capacity of a group of people or an organization to use knowledge effectively to achieve desired outcomes can be understood as a "social technology," an essential counterpart to the "hard" or "physical" technologies and formalized knowledge that are viewed as the standard outputs of research. Social technologies can be seen as embodying the "know-how" that incorporates available resources (including physical technologies) to achieve a goal (Nelson and Sampat, 2001), as well as the value systems that inform and guide action (Simon, 1997). The global eradication of smallpox required both effective, mass production of freeze-dried vaccines, and surveillance and containment strategies that allowed outbreaks to be identified, isolated, and treated. The former, physical technology was neither more nor less crucial than the latter, social technology (Hopkins, 1989). In considering the three examples sketched above, each is characterized by a focus on physical technologies, and a relative neglect of the social technologies and value systems—the capabilities of users—that determine if and how the physical technologies will be used. In terms of scientific and technological outputs, each example may be—and commonly is—considered to be a resounding science policy success. In terms of social outcomes, however, each bears scars of ongoing failure.

Elevating social technologies to the same level of significance as physical technologies does impose an additional analytical burden on science policy makers: they must understand not only the institutions and actors who conduct the research that they fund, but also the institutions and actors who might (or might not) use this information. Yet, just as science policy decisions help to create new research institutions, fields, and communities through funding mechanisms, so might they more routinely seek to create the social technologies that can help turn knowledge and technology into outcomes. This was precisely the intent of the Smith-Lever Act of 1914, which created the cooperative extension service—a social technology—to enhance communication between farmers and researchers. Seventy-five years later, manufacturing extension services were created by the U.S. government to help ensure that small businesses are better linked to technological innovators (PL 100–418, 1988). But in general science policy decision making has not been in the business of encouraging the social technologies that help steer the creation and use of knowledge and physical technology toward desired outcomes.

New evaluation procedures must also be devised to test the capacity of research programs to achieve stipulated outcomes. Amazingly, no such procedures are well developed. This neglect is in part an acknowledgment of the difficulty of the task, yet so little effort has been applied to this end that it would be premature to suggest useful tools cannot be produced. One preliminary effort by Catherine Lyall et al. (2004) presents a model of the interactions between research producers and users that asks systematic, retrospective questions about communication, end-user needs, uptake of results, and general relevance of results, to assess actual social impacts of research activities. Another early effort, termed Public Value Mapping (PVM; Bozeman, 2003), would use a case-based approach to assess, prospectively, the assumptions imbedded in claims about the outcomes of research. PVM asks:

> Given a set of social goals and missions, ones in which science is intended to play a major role in bringing about desired social outcomes, are the strategies for linking and mobilizing institutions, network actors and individuals viable ones? Is the underlying causal logic of program or mission sound? Are the human, organizational, and financial resources in place to move from science and research to application to desired social outcome? (Bozeman, 2003)

If such questions cannot be answered, how can any reasonable claim be made that a research investment or program will lead to a particular benefit?

The overall point is that it is not terribly difficult to conceptualize methods for better understanding how knowledge production and physical technologies relate to knowledge users and social technologies, and that such relations may often be a strong proxy for social outcomes. But such work is in its infancy.

Any effort to understand the sources of failure in the three science policy cases outlined above would quickly focus on the role of socially and economically disenfranchised populations. Such populations are ill-positioned to take advantage of employment opportunities in the high-technology, ultracompetitive marketplace, nor are they able to afford the products of that marketplace in addressing their health problems, nor is the knowledge developed about climate behavior able to mitigate their vulnerability to climate and weather phenomena. The requisite social technologies are absent. We are back to our original question: If science is promoted for its ability to create positive outcomes, yet such outcomes are determined by factors extrinsic to science, on what basis can the promise of benefits be made?

The question now yields a fourth way we might reconceptualize science policy: as one component in a portfolio of policy approaches for confronting a social problem. By starting with a careful delineation of the problem to be solved or the outcome to be pursued, a number of different, although perhaps closely related, policy paths might be identified, one or more of which would be scientific research. By viewing science along with other approaches, the contextual embeddedness of science policy decisions would become more apparent. Revisiting the example of the malaria-blocks-development hypothesis, promoted nowadays by the Commission on Macroeconomics of the World Health Organization, if the desired outcome is economic growth, then one policy path would be elimination of malaria, but another surely would be reform of land tenure patterns, market asymmetries, etc. In comparing these two approaches, it might be decided that eliminating malaria is more practicable, but it would also be clear that this would not likely yield the economic result that is promised by an approach to science policy that views the malaria vaccine itself as an economic instrument.

When particular social outcomes are sought, science policy decisions might appropriately be considered alongside other types of policy decisions. Tradeoffs might well be appropriate. The institutional obstacles to such a process are significant, because science policy decision making is, by design, often isolated within particular agencies and organizations of government. Yet it is not very hard to visualize decision tools that could at the very least create the possibility of a discourse that contextualizes science policy.

For example, Garfinkel and others (in review) have developed a prototype "societal outcomes map for health research and policy" to illustrate the various elements that contribute to a particular desired health outcome. Such a map allows stakeholders to visualize alternative pathways, trade-offs, and options that might be chosen in pursuit of an outcome. In the prototype map, which considers the issue of perinatal health and the desired outcome of healthy babies, policy paths include programs to improve nutrition for pregnant women, screen the newborn for diseases, and conduct research on the causes of birth defects (Figure 3). All of these, of course, may be worth pursuing, but understanding and comparing what is known about the costs, benefits, track record, and potentials of each can allow choices to be considered that are not available in the decontextualized science policy environment today.

The ideology of science policy derives directly from an ideology of science itself where scientists are viewed as comprising an autonomous republic whose conduct and governance is largely an internal matter, appropriately carried out in isolation from other societal activities. When this ideological foundation is combined with the belief that benefits accrue inevitably and automatically from the creation of knowledge and innovation, a strong case can be made that science policy decisions need not be particularly sensitive to or aware of the social context within which knowledge and innovation are used. But specific examples of the failure of science policy decisions to achieve promised social outcomes, as well as a rich body of theoretical and empirical work showing the complex feedbacks among the production of knowledge and innovation, their use, and social outcomes, strongly argue for a more contextually aware science policy process than currently operates in most settings. Some tools and methods that can enable this contextualization are beginning to be tested. And much can be learned from a variety of at least partial successes in such outcome-focused areas of science as agriculture and public health.

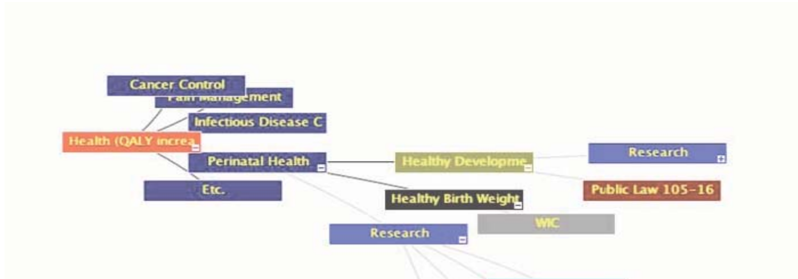


Figure 3a

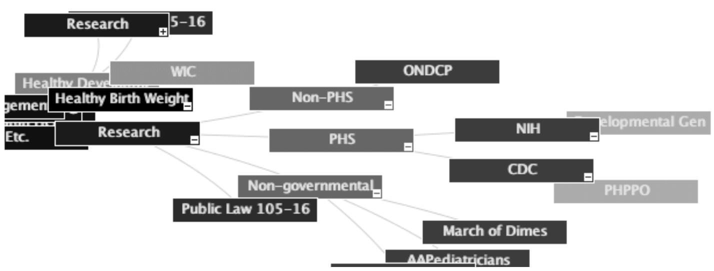


Figure 3b

This figure captures two screens of a web-based interactive societal outcomes map for health and health-research policy. The top panel (Figure 3a) depicts a "high-level" constellation of health concerns known to impact quality-adjusted life years (QALYs), including cancer control, infectious diseases, and, our concern here, perinatal health. many factors are known or thought to contribute to perinatal health (the time in development starting around 28 weeks of pregnancy until about a week after birth, although some workers define a much longer post-partum period as being perinatal). Here (Figure 3b) we indicate only three: healthy development (a generic indicator of, e.g., a lack of disease-causing genes in the fetus, a healthy mother, a "clean" environment, etc.); healthy birth weight (a specific indicator of certain kinds of environmental inputs but most importantly a measure of calories consumed by the mother during pregnancy; this is particularly relevant in developing countries and poor communities in developed countries); and a panoply of "unknowns" indicated here under the rubric "research" to indicate where more needs to be known. Because the indicators "healthy development" and "healthy birth weight" are well-established, they link back to "perinatal health" by heavy, dark lines. The unknowns, where more research is needed, link back with a thin, light-colored line. This display of the map shows legislation written and agencies tasked to ensure perinatal health in the United States. Even in this small excerpt, note the wide variery of contributors beyond, e.g., the NIH, frequently thought of as the main contributor to health in the United States. (In the animated version of the map, one may "click through" these agency boxes to see the specific programs, budgets, etc., that each piece of legislation or agency offers.)

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