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Funding Scientific Knowledge
Selection, Disclosure, and the Public-Private Portfolio

Joshua S. Gans and Fiona Murray

1.1 Introduction

Funding agencies, philanthropists, and corporations agree that the funding of scientific progress provides essential knowledge for solving major global challenges. However, fifty years after the original *Rate and Direction* volume articulating the importance of public (and private) research funding (Arrow 1962), scholarly disagreement continues over the precise balance of funding, appropriate selection criteria for each funder, and the disclosure conditions to be enforced. In this chapter, we review the choices funders have made over the past fifty years and provide a model that yields an overarching framework in which to consider the diverse perspectives for research funders.

Over the past century, scholars and policymakers have provided at least two distinctive arguments for the public support of research—in particular, for basic research. The first contention, most famously articulated by Arrow, is grounded in the idea that there is a "funding gap" between the level of private support for research and the socially optimal level of its provision (1962). The second, more recent argument highlights differences in the institutional foundations of knowledge production, particularly as they pertain

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to openness and disclosure (see Dasgupta and David 1994). Even if private funds are allocated to a critical research project under the "openness gap" argument, only public funding and the institutional arrangements that it supports enable optimal levels of disclosure and thus ensure effective accumulation of knowledge (Gans, Murray, and Stern 2010). These perspectives point to the importance of the *selection criteria* used by public (and private) funders in shaping both the overall level of funded research projects and their composition (across dimensions of contribution to understanding and to usefulness). They also suggest a second dimension to be considered: the *disclosure criteria* that funders (public or private) impose as they deploy their funding. The two schools of thought, however, fail to articulate how the evolution of private and public research funding have created a tangled relationship between openness and innovation, whereby corporate protection of intellectual property can lead to greater innovation and disclosure, while public funding can potentially restrict innovation and disclosure. A comprehensive review of the policies used by the major government and nonprofit funding institutions can highlight how the relationships between project selection and disclosure policies can affect outcomes for future research and innovation.

This chapter uses a theoretical model as a framework within which to examine and compare relationships between funders, including how differences shape the levels of research funding, the balance of public-private projects, and the disclosure of research results. Not only does this approach synthesize an otherwise complex area of enquiry, it also provides us with a much richer context within which to explore the role of public funders, the emerging role of philanthropic funding, and the potential for public funding to crowd out private sector research.

The historical arguments for the importance of public support of research provide the starting point for our chapter. Arrow first articulated the funding gap or *selection* perspective in 1962, arguing that since private incentives to fund research are well below social incentives, without public funding the rate of inventive activity will be suboptimal and its direction biased toward more applied, "close to market" outcomes. Even prior to this conceptualization, Nelson had argued that:

> if the marginal cost of research output is assumed to be no greater in non-profit laboratories than in profit-oriented laboratories, and if industry laboratories are assumed to operate where marginal revenue equals marginal cost, then the fact that industry laboratories do basic research at all is itself evidence that we should increase our expenditure on basic research. (1959, 304, emphasis in original)

In other words, the very fact that private activity continues is evidence that public grants to support invention do not displace private invention. Fifty years on, the theoretical rationale for public support of invention remains unchallenged; in the years following World War II, such public intervention has been recognized and institutionalized (Bush 1945). Nonetheless, public funders often find themselves at odds with policymakers and other constituencies as they balance the need to fund areas of basic research avoided by the private sector against the political need for real-world impact. Take, for example, the critique of cancer research spending by the National Cancer Institute (NCI): Forty years after Nixon's "War on Cancer," many have accused the NCI of overemphasizing basic research to the detriment of more translational projects that maximize patient impact (Groopman 2001). On the other hand, when agencies shift their funding toward near-term, mission-oriented R&D projects, they are criticized for crowding out what industry would have done otherwise or for funding (seemingly) redundant efforts.

An alternative openness gap or *disclosure* perspective rationalizes public funding on the basis that a stream of private sector research is not optimal for ensuring levels of disclosure that can spark longer-term innovation. Only publicly funded, public-sector researchers can ensure the broad disclosure of research findings that leads to long-term growth (Romer 1990). The institutional foundations that establish the setting, incentives, and mechanisms to ensure such freedom and openness have been elaborated by David (2008) and others. In addition, Mokyr (2004) emphasizes the importance of public funding for ensuring long-run knowledge accumulation and intertemporal spillovers. Together, these lines of scholarship build on and broaden Nelson's notion that basic research requires conditions of openness and emphasize that any type of research that is disclosed is far more socially valuable than research held secret. Disclosure is achieved through the contractual provisions of research funding and, more broadly, because of the norms and incentives for openness found in published research institutions. (Dasgupta and David 1994; David 2008). Moreover, different types of disclosure regimes can arise and even coexist, regardless of whether research is strictly basic or applied in nature.

Potential conflicts between the *selection* versus *disclosure* perspectives are most vividly illustrated by the calls to halt public funding of the Human Genome Project following the announcement that the for-profit company Celera would also undertake full genome sequencing and "race" the public effort to complete sequencing. Observers argued that the public funding was now redundant and wasteful. In response, public funders sought to emphasize and enhance the commitment of the public project to openness, rapid and full disclosure of sequencing data, and the provision of an entire information infrastructure for future generations of researchers—a claim that strongly countered Celera's tight control of their data (Williams 2010; Huang and Murray 2009).

To reconcile these two seemingly distinct perspectives on public research funding, we develop a theoretical model that considers demand and supply of research funds in relation to disclosure requirements. Our contention is that the conditions attached to public support of inventive activity will impact both on the mix of projects funded and the openness of those projects. This is achieved through a market that emphasizes the preferences of both the funders and the scientists in choosing the types of projects and disclosures they prefer. To elaborate this argument, we model the supply of funds, as determined both by the selection criteria of funding organizations and the disclosure conditions that organizations impose for funding. As we will detail later, we define the space in which funders select projects along two dimensions: usefulness to specific problems and contribution to basic knowledge (Stokes 1997; Murray 2002). The demand for funds comes from scientists who choose to accept or reject funding offers based on their other options and preferences for disclosure. This approach brings scientists back into a literature that has been centrally focused on funders and has only paid limited attention to the funding preferences of scientists themselves. Our analysis of disclosure relies on the assumption that knowledge can often be disclosed (or not) according to four different regimes: secrecy, publications, patents, or patent-paper pairs (Murray and Stern 2007; Gans, Murray, and Stern 2010). Our contention is that public funders (governmental and nongovernmental) do not contribute to invention solely by adding resources to knowledge production projects. Their impact arises in the way they select projects for support *and* in the conditions they attach to the disclosure and commercialization of those projects. Both selection and disclosure, we argue, have an impact on the direction of inventive activity. In our model some projects—depending on their characteristics—are able to attract private funding. The supply of those funds is determined by the selection criteria of funding organizations and by those organizations' choice of (disclosure) conditions on funding. The demand for private funds is shaped by the relative desirability of accepting private funds.

Our context for understanding the role of public and private research funding is a period in which total US R&D expenditures have risen from $72.5 billion in 1962 (the year of the *Rate and Direction* volume) to US$350 billion in constant 2000 dollars by 2008 (S&E Indicators, Figure 4-1). This represents not simply a rise in federal (public) funding, which grew around $47 billion to over $85 billion (over the same period), but also in R&D funding from industry which experienced its highest growth, from being about 50 percent of the federal contribution level ($23 billion) to dwarfing the federal contribution at over $200 billion. Given the high levels of private sector funding of R&D, the possibility that at least some public funding is purely duplicative of enlarged private efforts only strengthens the case that opportunities exist to target public funding to promote more socially valuable inventive activity. When combined with the question of what conditions should be attached to research contracts (for example, disclosure and commercialization), this approach provides a framework within which to examine and inform research selection and research contract design by public (government and philanthropic) funding agencies.

We pursue our analysis by gathering (the somewhat sparse) empirical evidence and developing a theoretical model. Our findings motivate a broader agenda for the study of the contract design problem facing research funders. To this end, our chapter does three things: First, in sections 1.2 and 1.3, we provide an overview of preferences of funding organizations across different types of research projects and disclosure regimes: Section 1.2 reviews the selection criteria in government and nongovernment funding organizations—specifically focusing on their choice of projects along the two dimensions of scientific merit and immediate applicability. Then in section 1.3, we examine conditions for disclosure and commercialization of research project outcomes. In section 1.4, we provide a model of the demand and supply of public research funds. Finally, in section 1.5, based on our analysis, we outline an agenda for future research. This agenda is motivated by the fact that we have limited knowledge of the actual outcomes—selection and openness—of publicly funded projects as well as the baseline trade-offs that our theoretical model has identified.

1.2 How Public Institutions Select Academic Projects for Funding

In prescribing the role of public research support (in universities and elsewhere), Nelson, Rosenberg, and others have classified research projects along a continuum from basic to applied.[1] Under this schema, a key concern for public funders and academic observers is that private funders pursued too little basic research relative to their emphasis on applied "mission-oriented" research. The funding landscape turns out to be more complex: First, industry itself provides funding to universities to undertake research. Second, industry also does some basic research. Third, public funding is spent in academia on both basic research and more near-term, mission-oriented objectives. For example, some projects given government funding, such as the development of theories of plate tectonics or the big bang theory (funded by the National Science Foundation [NSF]), are explicitly generated to advance basic scientific understanding. Others have been focused specifically on meeting particular short-run practical objectives, such as the Department of Defense's (DoD) funding of gallium arsenide RF technology to enable cellular commercial infrastructure. Projects such as the Human Genome Project (noted earlier) were funded by the Department of Energy (DOE) and the National Institutes of Health (NIH) to generate knowledge considered useful *and* scientifically interesting. Not confined to the life sciences, research on chip design in the 1960s and 1970s (funded by

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[1] See also the definition formalized in 1963 in the Frascati Manual of the Organization for Economic Cooperation and Development (OECD).

the Defense Advanced Research Projects Agency [DARPA]) was also considered to be critically useful *and* scientifically important.

Given the complexity of the funding choices previously described, the simple basic-to-applied continuum as a model of selection is too simple to capture the current research landscape *and* fails to capture important findings in scientific history. As an alternative, we have chosen to consider a two-dimensional space for projects characterized by the degree of scientific merit on one dimension and the extent of immediate valuable application on the other. In other words, research projects cannot simply be characterized as basic (contributing to the advance of scientific knowledge) or applied (leading to immediate applications) but may also involve both: Galileo not only developed significant scientific insights that contributed to astronomy while observing the moons of Jupiter, Venus, and other plants; he also made useful advances in optics with implications for the nautical community (Biagioli 2000). Another eponymous example of this blurring between basic and applied research is Pasteur's simultaneous discovery of the small pox vaccine and advances in microbiology. His work, like Galileo's, has been described as lying in Pasteur's Quadrant (Stokes 1997). (See figure 1.1.)

By mapping research projects along two dimensions, their contribution to fundamental advances in knowledge and their application to useful problems, we can define (at least) three distinct classes of research (see Stokes 1997):

- Pure basic research (exemplified by the work of Niels Bohr, early twentieth century atomic physicist)
- Pure applied research (exemplified by the work of Thomas Edison, inventor)
- Use-inspired basic research (described as Pasteur's Quadrant)

		Immediate Application	
		NO	YES
Contribution to Fundamental Knowledge	YES	Bohr's Quadrant	Pasteur's Quadrant
	NO	Other research!	Edison's Quadrant

Fig. 1.1 Selection matrix of knowledge production projects

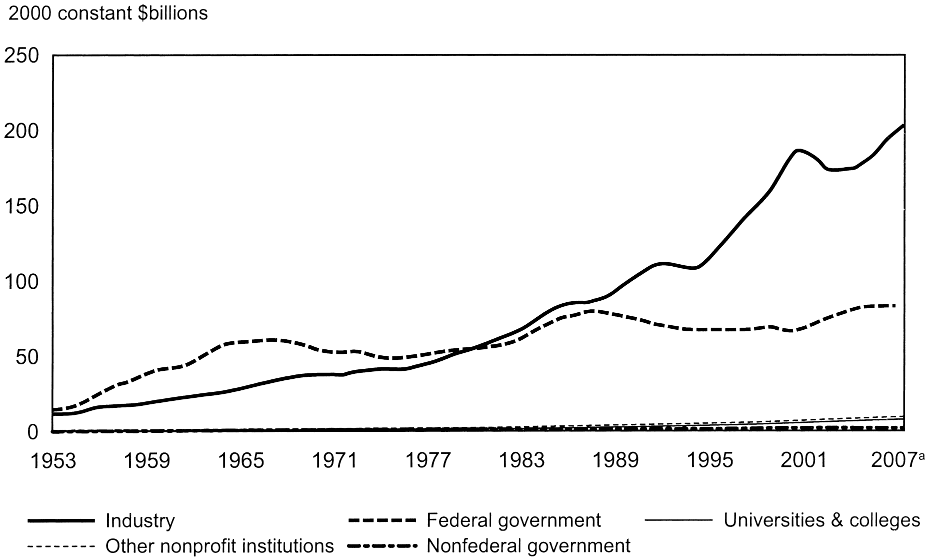

Fig. 1.2 R&D in 2000 constant $billions by source of funding

[a]Figures for 2007 are estimates.

Source: National Science Foundation, Division of Science Resources Statistics, National Patterns of R&D Resources (annual series).

The criteria used by funding organizations in the selection of their research portfolio have been the subject of surprisingly little empirical analysis; however, it is clear that there is no simple mapping of public (and private) funding to specific quadrants as defined earlier. In what follows, we therefore provide the broad context for public R&D funding (to universities) and data to elaborate trends in the fifty-year period since the *Rate and Direction* volume (1962).

As figure 1.2 illustrates, United States federal funding (the major source of public funding in the United States) has grown fourfold in this period. Not all of this funding flows to universities; they perform about 10 to 15 percent of the total (public and private) research with around 50 to 60 percent of this funding coming from public federal sources and 5 percent from private sources.[2]

1.2.1 Public Funding—Federal Agencies

University-based academics perform more than 60 percent of the research funded by the federal government (with much of the remainder by government laboratories)—what amounts today to approximately $40 bil-

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[2] One note, however: because private funders generally do not use public "calls for proposals," information on their selection criteria are limited.

lion annually. The following graph (fig. 1.3) illustrates both funding agency sources and research performer. It highlights that the majority of funds are disbursed via four major funding agencies (who receive their budget via congressional appropriations). In recent years, the NIH has dominated federal R&D, followed by the NSF (Clemins 2010). The DoD is the third-largest sponsor of academic research (when only "science and technology" funding is included), with the DOE distributing a small (but growing) budget to academia.[3]

1.2.2 Selection Criteria of the Four Major Funding Agencies

The National Science Foundation—Funding Bohr's Quadrant

At its current funding level, the NSF accounts for about 20 percent of all research funding in academic institutions—one third of all public federal funds. The NSF and the funds it provides are most closely associated with a single funding Quadrant—"Bohr's Quadrant"—and uses as its selection criteria measures long-term scientific merit. At the broadest level, this reflects its founding mission, as articulated in 1945 in the letter written by Vannevar Bush—later to become the first director—to President Truman. In it, he articulated the "Endless Frontier"—the power of public (government) support for basic research to advance our understanding. While formulated as ultimately leading to innovation, economic growth and wealth creation, at its core Bush and his supporters established the NSF on the understanding that advances in knowledge must be funded in their purest form. Thus, the funding for basic research in US academia was established in its modern form.

The NSF awarded its first grants to academics in 1952 and since then the agency's mission has remained "to promote the progress of science; to advance the national health, prosperity, and welfare; to secure the national defense."[4] The funding criteria focus on their mission "chiefly by issuing limited-term grants—currently about 10,000 new awards per year, with an average duration of three years—to fund specific research proposals that have been judged the most promising by a rigorous and objective merit-review system."[5] To be specific, the NSF defines its goals as:

> discovery, learning, research infrastructure and stewardship—provide an integrated strategy to advance the frontiers of knowledge, cultivate a world-class, broadly inclusive science and engineering workforce and expand the scientific literacy of all citizens, build the nation's research capability through investments in advanced instrumentation and facilities, and support excellence in science and engineering research and education

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[3] The DoD Science & Technology (S&T) spending includes basic and applied research, medical research, and technology development categorized as 6-1 "basic," 6-2 "applied," and 6-3 "technology development."

[4] http://www.nsf.gov/about/glance.jsp.

[5] Ibid.

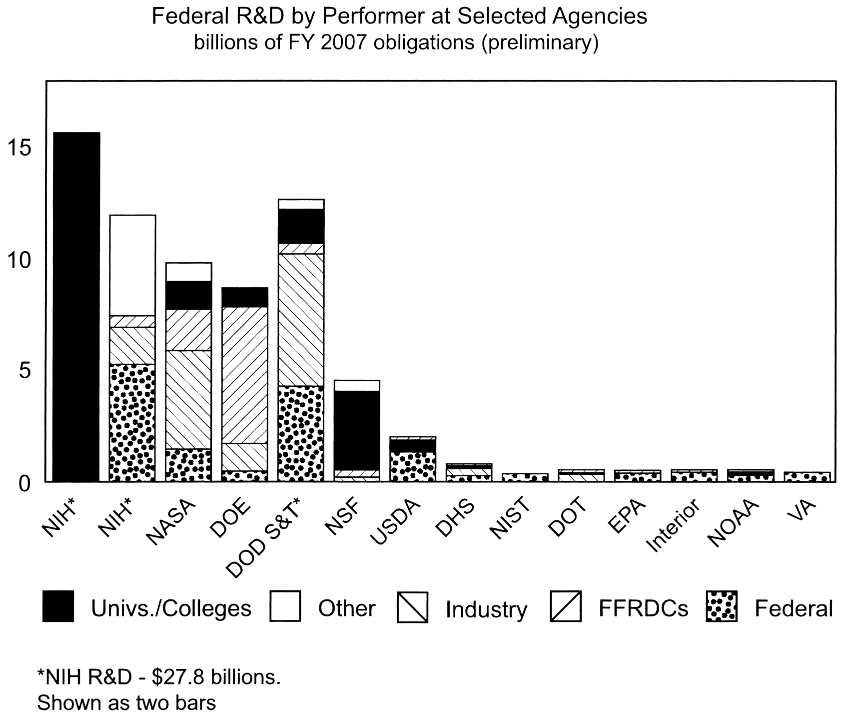

Fig. 1.3 Federal R&D by performer at selected agencies

Source: AAAS, based on NSF, Federal Funds for Research and Development, Fiscal Years 2005, 2006, and 2007, 2008. The R&D includes research, development, and R&D facilities. *DOD R&D in "6.1" through "6.3" categories. Feb. '08 © 2008 AAAS.

> through a capable and responsive organization. We like to say that the NSF is "where discoveries begin."

These goals led the NSF in the 1950s to fund a series of national observatories (1955), the South Pole Station (1957), and in the 1980s, the Internet backbone. In addition to major research infrastructure projects, most NSF funding is disbursed in the form of competitive grants to individual investigators. Its selection criteria highlight the intellectual merit of the proposed activity as well as the broader impacts resulting from the proposed activity in their proposals. However, these impacts are also defined not in terms of usefulness (in an Edisonian sense) but rather their contribution to education and training; in other words, the NSF funds Bohr's Quadrant. More specifically, the NSF review panels guide applicants to address two questions, both emphasizing knowledge advancement over applicability or usefulness:[6]

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[6] http://www.nsf.gov/pubs/policydocs/pappguide/nsf10_1/gpg_3.jsp.

- *What is the intellectual merit of the proposed activity?* How important is the proposed activity to advancing knowledge and understanding within its own field or across different fields? How well qualified is the proposer (individual or team) to conduct the project? (If appropriate, the reviewer will comment on the quality of prior work.) To what extent does the proposed activity suggest and explore creative, original, or potentially transformative concepts? How well conceived and organized is the proposed activity? Is there sufficient access to resources?
- *What are the broader impacts of the proposed activity?* How well does the activity advance discovery and understanding while promoting teaching, training, and learning? How well does the proposed activity broaden the participation of underrepresented groups (e.g., gender, ethnicity, disability, geographic, etc.)? To what extent will it enhance the infrastructure for research and education, such as facilities, instrumentation, networks, and partnerships? Will the results be disseminated broadly to enhance scientific and technological understanding? What may be the benefits of the proposed activity to society?

More recently, the NSF has initiated a new mechanism—EAGER—focused on early stage research. However, this is not a move toward application. Instead, it is intended to move researchers into more high risk-high return areas of Bohr's Quadrant by supporting "exploratory work in its early stages on untested, but potentially transformative, research ideas or approaches."[7]

The NIH, DoD and DOE—Funding Multiple Quadrants

The more mission-oriented funding for academic research provided by the NIH, DoD and DOE stands in contrast to the NSF. All three agencies' focus on their explicit mission-based approach (at least in theory) pushes them to evaluate and select projects along criteria of basic intellectual merit and immediate mission-oriented impact. However, in the mix of funding decisions, projects have been funded in Bohr's and Edison's Quadrants as well as Pasteur's Quadrant.

National Institutes of Health

As of 2010, the NIH budget reached over US$25 billion (excluding American Recovery and Reinvestment Act [ARRA] funding) with more than 80 percent funding research undertaken at over 3,000 US universities and research institutions.[8] The need to spend its appropriations through

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[7] http://www.nsf.gov/pubs/policydocs/pappguide/nsf10_1/gpg_2.jsp#IID2.

[8] Research grants are defined as extramural awards made for Research Centers, Research Projects, Small Business Innovation Research/Small Business Technology Transfer (SBIR/STTR) Grants, and Other Research Grants. Research grants are defined by the following activity codes: R, P, M, S, K, U (excluding UC6), DP1, DP2, D42, and G12.

project selections that blend scientific knowledge advancement with immediate application is evident in the current NIH mission "to improve human health by increasing scientific knowledge related to disease and health."[9] In its past history, the NIH was more mission-oriented and at the outset more closely focused on immediate applications of research to critical social problems; that is, it was strongly associated with Edison's Quadrant. In 1798 the Marine Hospital Service, which served as the founding organization of today's NIH, was established by President John Adams for the treatment of seamen and (later) officers of the US Navy. Its role in application-focused research was initiated almost 100 years later when Congress appropriated funds to study the causes of epidemic diseases, "especially yellow fever and cholera."[10] This was rapidly followed in 1879 by the establishment of the first comprehensive medical research effort on a national scale and the creation of the National Board of Health. Among its first research investments were a bacteriology laboratory on Staten Island focused on useful research. By 1918, the research program expanded beyond communicable diseases and extended its grants to outside institutions (thus establishing the precedent that the federal government might turn to scientists other than their own employees in institutions around the country for research assistance through a grant-making mechanism).[11]

The shift in orientation away from research of immediate practical application toward Pasteur's Quadrant and more basic contributions to the advancing of knowledge in Bohr's Quadrant can be traced to the 1950s and the rise of molecular biology. This field offered a deep knowledge base for the study of health and disease and for the development of specific treatments and cures (Judson 1979). Not surprisingly, it led to the NIH's hybrid goal of research to "advance the understanding of biological systems, improve the control of disease, and enhance health." Nonetheless, the current orientation is toward more "Bohr-like," less problem-oriented research. This orientation is evident in the criteria outlined to external peer reviewers: In selecting external awardees, the NIH uses a peer review system as legally required through sections 406 and 492 of the PHS Act with an underlying system to "provide a fair and objective review process in the overall interest of science" (NIH Grants Policy Statement [12/03], 7). Surprisingly, given the orientation toward practical applications as well as basic knowledge advance, the NIH review criteria are strikingly similar the NSF. Five selection criteria are defined in the Congressional guidelines:[12]

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[9] NIH Grants Policy Statement General Information 12/03.

[10] NIH Almanac.

[11] Today the NIH allocates awards (for research rather than infrastructure) through PAs or RFAs. A PA describes new, continuing, or expanded program interests. An RFA is a more targeted solicitation focused on well-defined scientific areas or for a one-time competition.

[12] http://grants.nih.gov/grants/policy/nihgps_2003/NIHGPS_Part3.htm#_Toc54600045.

- *Significance:* Does this study address an important problem? If the aims of the application are achieved, how will scientific knowledge be advanced? What will be the effect of these studies on the concepts or methods that drive this field?
- *Approach:* Are the conceptual framework, design, methods, and analyses adequately developed, well integrated, and appropriate to the aims of the project? Does the applicant acknowledge potential problem areas and consider alternative tactics?
- *Innovation:* Does the project employ novel concepts, approaches, or methods? Are the aims original and innovative? Does the project challenge existing models or develop new methodologies or technologies?
- *Investigator:* Is the investigator appropriately trained and well suited to carry out this work? Is the work proposed appropriate to the experience level of the PI and other researchers (if any)?
- *Environment:* Does the scientific environment in which the work will be done contribute to the probability of success? Do the proposed experiments take advantage of unique features of the scientific environment or employ useful collaborative arrangements? Is there evidence of organizational support?

The lack of mention of immediate application is striking. Specific funding choices at the level of particular grant mechanisms emphasize this shift toward a basic knowledge orientation. For example, in selecting projects in the R21 category (Exploratory Research Grant Program) that, like the NSF EAGER grants, are designed to support "novel scientific ideas or new model systems, or technologies that have the potential for significant impact on biomedical . . . research," reviewers are directed to focus their evaluation on the "conceptual framework, the level of innovation and the potential to significantly advance our knowledge."

Department of Defense

The United States DoD spent $82 billion on research, development, testing, and evaluation (RDT&E) in 2008—nearly 50 percent more than the rest of the federal government combined.[13] Little of this funding reaches academic institutions—only $2 billion to academia for research purposes—2.1 percent of the DoD's RDT&E budget to so-called basic research, and 5.3 percent to applied research (DoD Budget: Fiscal Year 2009, 2008).

The limited emphasis on research in academia is further reflected in its organizational structure; university research is one of several mandates supported by one of four organizations within the Research Directorate, which

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[13] The DoD classifies RDT&E into seven activities: basic research, applied research, advanced technology development, advanced component development and prototypes, system development and demonstration, RDT&E management support, and operational system development (DoD Financial Management Regulation 2008).

itself is one of four directorates under the Office of Defense Research & Engineering. Nearly all of the basic research and much of the applied research supported by the DoD is funded through DARPA, administratively independent from the Office of Defense Research & Engineering. Founded in 1958 as the Advanced Research Projects Agency in response to the launch of Sputnik and renamed DARPA in 1972, its mission is "to maintain the technological superiority of the U.S. military and prevent technological surprise from harming our national security by sponsoring revolutionary, high-payoff research bridging the gap between fundamental discoveries and their military use."[14] The DARPA can thus be squarely identified as searching for and selecting research opportunities in Pasteur's Quadrant or, when appropriate, in Edison's Quadrant—solutions to specific problems.

This problem orientation is evident in DARPA's organization around seven independent offices: Adaptive Execution, Defense Sciences, Information Processing Techniques, Microsystems Technology, and so forth. These offices are similar to the NIH's Institutional Centers in that they have independent missions and identify their own research agendas, but their selection criteria are more closely tied to their missions. Each office posts solicitations for research proposals in the form of Broad Agency Announcements (BAAs) (similar to NIH RFAs and DOE FOAs) in the specificity of research requested (DARPA Solicitations 2010). While the independence given to each office leads to variability within the evaluation criteria used across BAAs, the following criteria are present in each BAA, illustrating a tighter focus on useful applications in Edison's Quadrant:[15]

- *Overall scientific and technical merit:* The technical merit of the research and the soundness of the plan to perform it will be evaluated. The proposed research must be highly innovative and show promise of sufficient technical payoff to warrant the technical risk. The research must have the potential to make a radical impact on future technology. The proposed technical approach is feasible, achievable, complete, and supported by a proposed technical team that has the expertise and experience to accomplish the proposed tasks. Task descriptions and associated technical elements provided are complete and in a logical sequence with all proposed deliverables clearly defined such that a final outcome that achieves the goal can be expected as a result of award. The proposal identifies major technical risks and planned mitigation efforts are clearly defined and feasible.
- *Potential contribution and relevance to the DARPA mission:* The potential contributions of the proposed effort with relevance to the national technology base will be evaluated and its relevance to DARPA's par-

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[14] DARPA Mission 2010.

[15] Taken from DARPA-BAA-10-35 2010, DARPA-RA-10-76 2010.

ticular mission and methods assessed. Specifically, DARPA's mission seeks to maintain the technological superiority of the US military and prevent technological surprise from harming US national security. The DARPA aims to accomplish this by sponsoring revolutionary, high-payoff research that bridges the gap between fundamental discoveries and their ultimate military use.

- *Cost realism:* The objective of this criterion is to establish that the proposed costs are realistic for the technical and management approach offered, as well as to determine the proposer's practical understanding of the effort. The proposal will be reviewed to determine if the costs proposed are based on realistic assumptions, reflect a sufficient understanding of the technical goals and objectives of the BAA, and are consistent with the proposer's technical approach (to include the proposed Statement of Work). At a minimum, this will involve review, at the prime and subcontract level, of the type and number of labor hours proposed per task as well as the types and kinds of materials, equipment, and fabrication costs proposed. It is expected that the effort will leverage all available relevant prior research in order to obtain the maximum benefit from the available funding. For efforts with a likelihood of commercial application, appropriate direct cost sharing may be a positive factor in the evaluation.

Department of Energy

The smallest of the federal funding agencies in terms of funding of research in academia, the Department of Energy—unlike the NSF and NIH—has not historically been an organization devoted to funding research. Created in 1977 in response to the energy crisis of the 1970s from organizations that regulated the nuclear power industry and managed nuclear weapons development (Origins & Evolution of the Department of Energy 2010), the DOE has been "principally a national security agency" (DOE Program Offices 2010). It originally emphasized "energy development and regulation," "nuclear weapons research, development, and production" in the 1980s, and "environmental cleanup of the nuclear weapons complex, nonproliferation stewardship of the nuclear stockpile, energy efficiency and conservation, and technology transfer and industrial competitiveness" in the 1990s and early 2000s (Origins & Evolution of the Department of Energy 2010).

As of 2008, the DOE's mission is more focused on research and development, specifically "discovering the solutions to power and secure America's future" (DOE Summary of Performance and Financial Information 2009). In fact, the DOE now funds 40 percent of the basic research in the physical sciences in the United States, making it the single largest supporter of such research. (The majority of DOE supported research is performed internally in 17 national laboratories rather than in academic university labs.) Nonetheless, the DOE's strategic theme of science, discovery, and innovation accounted for only 16 percent ($4.1 billion) of its total program expenditures in 2009 (DOE Summary of Performance and Financial Information 2009). While this was supplemented by appropriations from ARRA, the DOE is not primarily focused on research funding despite its current mission.

The DOE selection criteria can be observed in its external grant solicitations through its Office of Science. Like the other mission-oriented agencies, the Office of Science is subdivided into six program offices, each reflecting a key mission area: Advanced Scientific Computing Research, Basic Energy Sciences, Biological and Environmental Research, Fusion Energy Sciences, High Energy Physics, and Nuclear Physics. Each office provides funding opportunity announcements (FOAs) focused on well-defined research goals. The DOE criteria for peer review (as legally required through the Office of Science Financial Program Rule [10 CFR Part 605 2006]) listed in descending order of importance, reflect funding in Edison's quadrant and, to a lesser extent than the NIH, Pasteur's Quadrant:[16]

- *Scientific and/or technical merit of the project:* For example, the influence that the results might have on the direction, progress, and thinking in relevant scientific fields of research; the likelihood of achieving valuable results; and the scientific innovation and originality indicated in the proposed research.
- *Appropriateness of the proposed method or approach:* For example, the logic and feasibility of the research approaches and the soundness of the conduct of the research.
- *Competency of the personnel and adequacy of proposed resources:* For example, the background, past performance, and potential of the investigator(s), and the research environment and facilities for performing the research.
- *Reasonableness and appropriateness of the proposed budget.*
- *Other appropriate factors, established and set forth in a notice of availability or in a specific solicitation.*

In response to the 2007 "Rising Above the Gathering Storm" report (National Academy of Sciences 2007), the America COMPETES Act established the Advanced Research Projects Agency-Energy (ARPA-E) within the DOE to "explore creative 'outside-the-box' technologies that promise genuine transformation in the ways we generate, store and utilize energy" (ARPA-E 2010c).

The ARPA-E is modeled after DARPA and received $400 million in initial funding through ARRA. Its mission is to "fund projects that will develop transformational technologies that reduce America's dependence on foreign

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[16] Basic Energy Sciences: Review and Selection of Research Projects 2010; 10 CFR 605.10.

energy imports; reduce U.S. energy related emissions (including greenhouse gasses); improve energy efficiency across all sectors of the U.S. economy and ensure that the U.S. maintains its leadership in developing and deploying advanced energy technologies" (ARPA-E 2010b). Furthermore, ARPA-E is not intended to support the traditional energy research agenda of the DOE, but to focus "exclusively on high risk, high payoff concepts—technologies promising genuine transformation in the ways we generate, store and utilize energy" (ARPA-E 2010b). The ARPA-E has released seven FOAs to date, six of which have a narrow research focus similar to traditional DOE FOAs (ARPA-E 2010c). However, "ARPA-E's inaugural program . . . was open to all energy ideas and technologies, but focused on applicants who already had well-formed research and development plans for potentially high-impact concepts or new technologies" (ARPA-E 2010a) suggesting a shift toward Pasteur's Quadrant with a specific focus on energy applications.

The ARPA-E uses a peer review process to select awardees with the following evaluation criteria:[17]

- *Impact of the proposed technology relative to state of the art:* The proposed technology must directly address one or more ARPA-E Mission Areas. Quantitative material and/or technology metrics must be proposed that demonstrate the potential for a transformational (not incremental) advancement in one or more energy-related fields. The applicant must demonstrate an awareness of competing commercial and emerging technologies and identify how its proposed concept/technology provides significant improvement over these other solutions. The applicant must have a strong and convincing transition strategy, including a feasible pathway to transition the program results to the next logical stage of R&D or directly into industrial development and deployment. The applicant must address the program-specific requirements identified for the Full Application phase as described in Section II of this FOA.
- *Overall scientific and technical merit:* The work must be unique and innovative. The proposed work should be high risk, but must be feasible. The applicant must demonstrate a sound technical approach to accomplish the proposed R&D objectives. The outcome and deliverables of the program, if successful, should be clearly defined. The applicant must address the program-specific requirements identified for the Full Application phase as described in Section II of this FOA.
- *Qualifications, experience, and capabilities:* The proposed Principal Investigator or technical team should have the expertise and experience needed to accomplish the proposed project. In addition, the applicant should have access to all facilities required to accomplish the R&D

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[17] DE-FOA-0000289; DE-FOA-0000290.

effort or has proposed the necessary missing equipment as part of the effort. The applicant's prior experience must demonstrate an ability to perform R&D of similar risk and complexity.

- *Sound management plan:* The proposed effort must have a workable plan to manage people and resources. Appropriate levels or people and resources should be allocated to tasks. The application should identify major technical R&D risks and have adequately planned mitigation efforts that are clearly defined and feasible. The proposed schedule should be reasonable. The applicant's prior experience in similar efforts must clearly demonstrate an ability to manage an R&D project of the same proposed complexity that meets the proposed technical performance within the proposed budget schedule.

Overall, it is clear that today's federal agencies select academic research projects across a mix of quadrants.

1.2.3 Public Funding—Philanthropic Foundations

Philanthropic foundations serve as an alternative source of public (i.e., not for profit) funding for research in academia. They have played a critical role in supporting US university research since the contributions of James Smithson to the establishment of the Smithsonian Foundation, which served not only to fund the now renowned museum but also one of the first extramural grant-making programs. According to his will (drafted in 1826) this Englishman's money would go "to the United States of America, to found at Washington, under the name of the Smithsonian Institution, an establishment for the increase and diffusion of knowledge."[18] After that time, wealthy individuals in the United States continued the practice of supporting academic research, selecting mainly on their interest in specific individual beneficiaries and missions. Many of the earliest gifts to university-based researchers focused on astronomy, botany, and zoology. In later years, more highly organized philanthropy shifted attention toward biomedical research.

The current landscape of philanthropic support for research includes a broad variety of criteria, with almost as much variation for funding university researchers as the federal agencies themselves. Traditionally, most foundations—for instance, the Sloan Foundation and the Howard Hughes Medical Institute, have followed selection criteria emphasizing scientific rather than applied outputs; Howard Hughes Awards are well-known for their provision of long-term support for high-risk research based on scientific merit and contributions to fundamental knowledge; that is, Bohr's Quadrant (see Azoulay, Graff Zivin, and Manso 2010).

The more recently founded Bill & Melinda Gates Foundation is a strik-

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[18] Available from http://siarchives.si.edu/history/exhibits/documents/smithsonwill.htm.

ing example of a foundation with significant resources that places a much greater emphasis on solving problems of immediate social and economic value. The overall foundation statement highlights a strong mission orientation by outlining its commitment to projects by asking the following questions:[19]

- What affects the most people?
- What has been neglected?
- Where can we make the greatest change?
- How can we harness innovative solutions and technologies?
- How can we work in partnership with experts, governments, and businesses?

In the arena of Global Health (which constitutes more than 60 percent of the $22 billion in funding that the foundation has committed from 1994 through 2010), the Foundation's priority areas are defined by disease. Its work in areas such as diarrhea, malaria, polio, and tuberculosis closely mirrors the priorities and emphasis of the NIH in the late half of the nineteenth century and early twentieth century. In selecting funding recipients, the Foundation uses criteria that are significantly at odds with the NIH (even in the same programmatic arenas) and emphasize problem-focus in Edison's Quadrant.

Like most of the federal funding agencies, the Gates Foundation also has a program to fund high-risk, high-reward research: the Grand Challenge Explorations program. At only $100k per project, the foundation emphasizes "unorthodox thinking . . . essential to overcoming the most persistent challenges in global health . . . to expand the pipeline of ideas to fight our greatest health challenges."[20] Not only is the mission of this program more tightly coupled to the production of useful knowledge to address key problems, but the funding criteria are also dramatically different from the approach used in federal funding. At the start of an Explorations program, a topic area is outlined. For example, a 2010 Grand Challenge Explorations theme was focused on new technology for contraception. The topic was defined with the articulation of a key "roadblock." Specifically, they state that:[21]

> there have been tremendous improvements in the reproductive health of men and women in the developing world. Nonetheless, many do not have access to health supplies and services that enable planning the number and timing of pregnancies, safe delivery of children, and management and treatment of sexually transmitted infections.

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[19] http://www.gatesfoundation.org/grantseeker/Pages/foundation-grant-making-priorities.aspx.

[20] www.grandchallenges.org/explorations/.

[21] http://www.grandchallenges.org/Explorations/Topics/ContraceptiveTechnologies/Pages/round4.aspx.

The Foundation argues that barriers to uptake arise because:

> current methods do not meet their needs. For those whose income is less than $2 per day, cost is an specially important issue . . . and side effect[s] that can occur [are] not acceptable in certain cultural contexts. Skilled health care workers are often unavailable in resource poor settings so self-administration or options that allow for non-medical staff—such as community health volunteers—can increase access to new methods.

They conclude with their statement for proposals:

> that are "off the beaten track," daring in premise, and clearly different from the approaches currently being developed or employed. Technologies or approaches should enhance uptake, acceptability and provide for sustained use; enable or provide for low-cost solutions; promote effective delivery and administration of new solutions; and ensure or enhance safety.

Proposals are not explicitly subject to traditional peer review. Instead, the review panel has "broad expertise and a track record in identifying innovations." Members may not be deep domain experts in the field. Review is executed in four stages: In stage 1, foundation staff review proposals to determine a match between the proposal and key needs described in the topic, or proposals considered to be more incremental advances. In the second step, external reviewers make evaluations, but rather than seek consensus, they can make funding recommendations based on the best proposals they see. Three criteria are deemed critical.[22]

- *Topic responsiveness:* How well does the proposal address a key need illustrated in the topic description?
- *Innovative approach:* Does the idea offer an unconventional, creative approach to the problem outlined in the topic?
- *Execution plan:* Is the work described feasible within the budget and time allocated for a Phase I GCE award and if successful, would it be sufficient to show a clear path to further support?

The Gates criteria, in contrast to all the federal funding criteria, illustrate a much tighter coupling for selection to specific areas of need and immediate application. More akin to the French wine industry funding much of Pasteur's work on fermentation, the criteria couple the hybrid generation of fundamental knowledge to the solution of specific problems, thus reemphasizing the degree to which—at least in selection—funders have a rich array of choices available to them as they establish selection criteria.

In figure 1.4 we map each of the agencies and several of their larger programs, as well as a number of the major foundations, into the two-by-two selection matrix outlined earlier. What is clear is that there is significant

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[22] Rules and Guidelines: Grand Challenges Explorations Round 4.

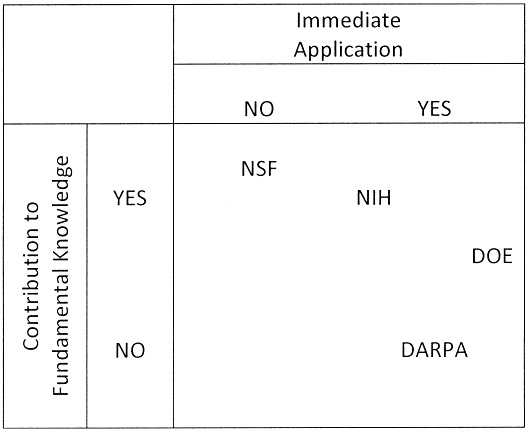

Fig. 1.4 Mapping federal funding to the selection matrix

diversity across the agencies, even among those three with a well-articulated mission orientation. And, among foundations there is even greater variation and a willingness to experiment with a broader space of selection criteria (although the effectiveness of these criteria, either in terms of selecting distinctively different research projects or achieving different outcomes, remains to be fully analyzed).

1.3 Disclosure and Commercialization

Disclosure is a key element in shaping the economic impact of investments in research by both the public and the private sector; however, the disclosure conditions imposed by funders received only limited scrutiny from policymakers and scholars until the 1980s. Contemporary scholarship brought the recognition that the mere production of knowledge was inadequate to ensure its role in knowledge accumulation: intertemporal knowledge spillovers require that knowledge be disclosed and accessible to others, a feature of knowledge production that is far from axiomatic (Mokyr 2004). What remains to be understood and analyzed in the context of the research funding is the range of possible disclosure choices, the preferences of researchers and funders for these conditions, and whether and how disclosure conditions influence the level and type of projects funded by the public and private sector respectively.

Building on the two-by-two framework elaborated in section 1.2, we argue that there exist at least four distinctive disclosure strategies; secrecy (nondisclosure), publication, patenting, and patent-paper pairs (Murray 2002). Each of these options map into several of the four research quadrants previously described. Specifically for research that lies in Pasteur's

Quadrant, all four disclosure strategies are viable alternatives—research that is useful and makes a contribution to fundamental knowledge can be patented or published (or both), but can also be subject to secrecy. For Bohr's quadrant, secrecy and publication are viable strategies. Edison's quadrant research can remain secret or be patented, as illustrated by the high levels of patenting achieved by Edison and his laboratory.

In what follows, we provide some insight into each of the four disclosure choices (for more detail see Gans, Murray, and Stern 2010). Nondisclosure or secrecy may be preferred by some funders (particularly those in the private sector or government agencies funding particular types of research with national security implications) but is generally not compatible with researchers in academia. Far from being a modern practice, secrecy was widely used by funders of research, particularly patrons who had utilitarian motives for maintaining at least some of the discoveries that they funded a secret (David 2008). Even in the case of Galileo, the telescopes he prepared for his patron were presented only at the Grand Duke's orders to the other European rulers (David 2008, 13). In later periods, researchers funded on botanical expeditions also maintained their plant specimens, drawings, and maps as secrets for their wealthy commercial sponsors (Stroup 1990; Schiebinger and Swan 2005). More contemporary examples of secrecy in government-funded research include the Manhattan Project—among the best known "secret" research projects undertaken by academic scientists. Most recently, the so-called "climategate" argument over research performed in the UK identified researchers at the University of East Anglia who had "an unacceptable culture of secrecy."[23] Indeed, as a leading analyst of medical science has argued, "secrecy in science reduces the efficiency of the scientific enterprise by making it harder for colleagues to build on each other's work" (Blumenthal et al. 2006).

The three disclosure strategies that provide an alternative to secrecy rely upon complex institutions to provide incentives for scientists and those who fund them to engage in disclosure: the patent system or *commercial science,* and the system of publications often termed *open science* (Dasgupta and David 1994).

Disclosure in patents is supported by commercial science, which, among other functions, provides incentives to ensure that knowledge locked within labs might instead be disclosed (Machlup and Penrose 1950; Kitch 1977; Scotchmer and Green 1990). As a quid pro quo for exclusionary rights of a limited term, patent holders (whether they be the funder or the researcher) must disclose knowledge at the level that enables a person "skilled in the art" to replicate that knowledge and potentially build upon it. This strategy is most likely to be appropriate for knowledge that is of immediate applica-

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[23] Chairman of the Science and Technology Committee blamed the University for encouraging a "reprehensible culture of withholding information."

tion (in Edison's or Pasteur's Quadrant), given the requirement for patent grant that an idea be not only novel and nonobvious but also useful. And, with the passage of the 1980 Bayh-Dole Act title to patents was clearly given to universities for researchers funded by the federal government, a norm that has extended to many other funders (with some institution specific variations).

For researchers working within academia, publication disclosure associated with open science is the dominant institutional logic: when knowledge is disclosed through scientific publication in the academic literature, researchers are rewarded with kudos and other private benefits (Dasgupta and David 1994; David 2008). In other words, to receive credit for the intellectual priority of their scientific discoveries, scientists publicize their findings as quickly as possible but retain no other rights over their ideas (Merton 1957). Of course, journals require that an idea make a contribution to fundamental knowledge, and therefore knowledge in Bohr's and Pasteur's quadrant are most likely to be potentially disclosed via publication. Interestingly (as we outline in more detail later), public funders rarely place publication *requirements* on those whom they fund, assuming instead that broader institutional norms promote publication.

The fourth disclosure strategy—patent-paper pairs—is widespread among academic scientists (using a variety of funding sources). When research projects are in Pasteur's Quadrant and lead to research of immediate usefulness and make a contribution to long-run knowledge, then we see many observe disclosure in the form of patent-paper pairs regardless of funding source (Murray 2002; Murray and Stern 2007). For example, with funding from Geron Corporation, Professor James Thomson from the University of Wisconsin developed both monkey and then human embryonic stem cells and disclosed the research in the form of an academic publication. However, only a few weeks prior to publication, he filed patents. The more formal disclosure requirements provided by funders do not, to our knowledge, explicitly make provisions for patent-paper pairs. Instead, by making provisions that allow for publication hold-up to enable patent filing, they implicitly acknowledge the possibility of patent-paper pairs and enable researchers, their universities, and the flow of funding to follow the complex timing requirements that enable disclosure through patent-paper pairs.

Disclosure outcomes are typically negotiated between researchers or their organizations (for example, universities) and funders as they match on particular research projects. A control rights approach to the selection of disclosure strategy has recently been developed by Gans, Murray, and Stern (2010). They argue that scientists and those who fund them have clear (and potentially diverging) preferences for disclosure. In particular, while researchers have strong preferences for disclosure in the form of academic publications (Stern 2004), some funders—particularly those in the private sector—may have expectations that research is disclosed through patents or may prefer secrecy. This disjuncture highlights the important role of public (versus private) support in shaping the conditions influencing the level of research dissemination (or patenting) as well as the level of inventive activity (Furman, Murray, and Stern 2010).

In what follows, we examine the ways in which funders (as well as researchers and the universities in which they are employed) shape the selection among the four disclosure strategies for knowledge generated by the projects they fund. The precise nature of these requirements can be defined either through formal contracts (as is typically now the case for private funding) or via informal normative expectations (as is broadly true for public funding, although specific regulations do exist).

1.3.1 Disclosure Criteria for Public Funding—Government Agencies and Foundations

If public funding agencies, particularly the federal government, have been vague with regard to their expectations around the selection of research projects, their stipulations regarding disclosure of the results of these projects is even less precisely articulated.

In broad strokes, our analysis suggests that government funders make few active provisions to limit *nondisclosure*; the National Science Foundation asks researchers to make best efforts in disclosure but has no formal requirement limiting secrecy. The specific contractual provisions hold few obligations of publication disclosure. The NSF outlines:

> 38. Sharing of Findings, Data, and Other Research Products
> a. NSF expects significant findings from research and education activities it supports to be promptly submitted for publication, with authorship that accurately reflects the contributions of those involved.
> b. Adjustments and, where essential, exceptions may be allowed to safeguard the rights of individuals and subjects, the validity of results, or the integrity of collections or to accommodate legitimate interests of investigators.

Overall, there is a strong adherence to the notion of autonomy and self-regulation for the scientific community. This is based both on a view that incentives for academic publication will eventually ensure that knowledge production will indeed be disclosed via publications, and through the use of publications as a selection mechanism for future awards.[24]

With regard to patenting, the regulations are more precise. Provided for by the Bayh-Dole Act, the National Science Foundation and other US govern-

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[24] Scotchmer and Maurer (2004) demonstrate that a reputation-based funding mechanism can substitute for a public funder's difficulty in evaluating research outcomes ex ante.

ment agencies have provisions for the patenting of inventions outlined in the Federal Register ([35 U.S.C. § 200 et seq.]).

Specifically:

> Unless otherwise provided in the award, if this award is for experimental, developmental or research work the following clause will apply:
> b. Allocation of Principal Rights
> The grantee may retain the entire right, title, and interest throughout the world to each subject invention subject to the provisions of this Patent Rights clause and 35 U.S.C. §203. With respect to any subject invention in which the grantee retains title, the Federal Government shall have a nonexclusive, nontransferable, irrevocable, paid-up license to practice or have practiced for or on behalf of the U.S. the subject invention throughout the world.

Of particular note is the requirement to disclose inventions to the NSF within two months (and include in that notification information about other publications and manuscripts).

> c. Invention Disclosure, Election of Title and Filing of Patent Applications by Grantee
> 1. The grantee will disclose each subject invention to NSF within two months after the inventor discloses it in writing to grantee personnel responsible for the administration of patent matters. . . . It shall be sufficiently complete in technical detail to convey a clear understanding of the nature, purpose, operation, and, to the extent known, the physical, chemical, biological or electrical characteristics of the invention. The disclosure shall also identify any publication, on sale or public use of the invention, whether a manuscript describing the invention has been submitted for publication and, if so, whether it has been accepted for publication, at the time of disclosure.

This is the most salient element of the contractual regulation of federal funding that *requires* rather than expects disclosure, although it is not clear whether in practice this is always fulfilled and there is considerable discretion on the part of investigators.

While the NSF rules are closely followed by other US federal funding agencies, more stringent disclosure requirements have been imposed by government agencies elsewhere such as the UK's Medical Research Council. They place a greater emphasis on publication as a strong expectation (BBSRC 2011):

> GC 23 Publication and Acknowledgement of Support
> The Grant Holder should, subject to the procedures laid down by the Research Organisation, publish the results of the research in accordance with normal academic practice.

This is augmented by specific provisions making publications themselves more available:

> AC30 Self archiving of publications
> For proposals (for grants or fellowships) submitted after 1 October 2006, electronic copies of any original research papers accepted for publication in a peer-reviewed journal, which are supported in whole or in part by MRC funding, must be deposited at the earliest opportunity, and certainly within six months of publication, in UK PubMedCentral. This applies whether the manuscript was submitted during or after the period of the grant. The condition is subject to compliance with publishers' copyright and licensing policies. Whatever possible, the article deposited should be the published version.

Some foundations follow a similar line and, in fact, use disclosures as critical inputs into funding decisions. For instance, the Sloan Foundation specifically requests tangible outputs "(such as number of students whose training or careers are affected, data collected, scientific papers produced) and outcomes (such as new knowledge, institutional strengthening, etc.)" or other measures of success including "big sales of a book, a prize awarded for research, a government grant to continue the project, web traffic, high enrollments, better salaries, etc." in evaluating grant effectiveness (Sloan Foundation 2008). Similarly, the criteria of the Gates Foundation (as it pursues a selection model that emphasizes immediate value) emphasize what they term "actionable measurement" in follow-on grant selection process but places no specific requirements on disclosure.[25]

1.3.2 Disclosure Criteria for Public Funding—Special Provisions of Defense Funding

In comparison to most public funding from government agencies and philanthropic foundations, research funding for defense-oriented research, including research funded by DARPA, places greater limitations on disclosure, particularly when associated with research of immediate application. Of course, as Senator Moynihan quoted in an address on Secrecy in Science to the American Association for the Advancement of Science in 1999:[26] "What is different with secrecy is that the public cannot know the extent or the content of regulation."[27] Thus it is difficult to precisely calibrate the extent of secrecy for defense research.

The secrecy (nondisclosure) of publically funded research can be required through the 1951 Invention Secrecy Act,[28] which empowers federal defense agencies to prevent the disclosure of new inventions that pose a potential national security threat by sharing with the United States Patent and Trade-

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[25] http://www.gatesfoundation.org/learning/Documents/guide-to-actionable-measurement.pdf.

[26] http://www.aaas.org/spp/secrecy/Presents/Moynihan.htm.

[27] Commission on Protecting and Reducing Government Secrecy, Secrecy: Report of the Commission on Protecting and Reducing Government Secrecy (Washington, D.C.: Government Printing Office, 1997), p. xxi.

[28] 35 U.S.C. § 181–188.

mark Office (USPTO) a classified list of sensitive technologies in the form of the "Patent Security Category Review List" (PSCRL).[29] Prior to this time, during World War I and throughout World War II, Congress authorized the USPTO to classify certain defense-relevant patent applications, and patent secrecy was used to maintain secrecy over information considered critical to national security particularly the Manhattan Project. The formal language of the 1951 statute is informative:

> Whenever publication or disclosure by the grant of a patent on an invention in which the *Government has a property interest* might, in the opinion of the head of the interested Government agency, be detrimental to the national security, the Commissioner upon being so notified shall order that the invention be kept secret and shall withhold the grant of a patent therefore under the conditions set forth hereinafter.
>
> Whenever the publication or disclosure of an invention by the granting of a patent, in which the *Government does not have a property interest,* might, in the opinion of the Commissioner, be detrimental to the national security, he shall make the application for patent in which such invention is disclosed available for inspection to the Atomic Energy Commission, the Secretary of Defense, and the chief officer of any other department or agency of the Government designated by the President as a defense agency of the United States. Each individual to whom the application is disclosed shall sign a dated acknowledgment thereof, which acknowledgment shall be entered in the file of the application.

A secrecy order not only prevents patent award and orders that the invention be kept secret, it restricts the filing of foreign patents, and specifies procedures to prevent disclosure of ideas contained in the application.[30] The number of patents subject to this treatment as of 2009 is just over 5,000 with 103 new secrecy orders imposed on patents in 2009.[31]

It is generally within the more narrow constraints of specific research funding contracts used by Defense funding agencies, particularly DARPA, that other disclosure limitations are imposed on researchers (in academia

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[29] It should be noted that this provision is not limited to ideas generated with federal funding. It can be imposed even when the application is generated and entirely owned by a private individual or company without government sponsorship or support.

[30] The inventor does have some recourse for compensation: According to Section 183, An applicant, his successors, assigns, or legal representatives, whose patent is withheld as herein provided, shall have the right, beginning at the date the applicant is notified that, except for such order, his application is otherwise in condition for allowance, or February 1, 1952, whichever is later, and ending six years after a patent is issued thereon, to apply to the head of any department or agency who caused the order to be issued for compensation for the damage caused by the order of secrecy and/or for the use of the invention by the Government, resulting from his disclosure. See the Project on Government Secrecy at http://www.fas.org/sgp/othergov/invention/index.html.

[31] See Invention Secrecy Statistics as reported annually by the USPTO available at: http://www.fas.org/sgp/othergov/invention/stats.html. Also, see Foerstel, Herbert N., *Secret Science: Federal Control of American Science and Technology.* Westport: Praeger, 1993, 165–172.

and elsewhere). All DARPA BAAs are composed of the same basic requirements (although details differ from office to office and announcement to announcement) regarding disclosure with the obligations and requirements on intellectual property, publications, and export control restrictions dependent upon whether the research is funded as basic research (6.1), applied research (6.2), or advanced technology development (6.3).

In general, all research performed on a university campus will have no publishing restrictions and is distinguished from proprietary research and from industrial development, "the results of which ordinarily are restricted for proprietary or national security reasons" (DARPA-BAA-10-35 2010). For research that meets the basic or applied classification, BAAs have a publication approval subsection under award administration information that states that it is "the policy of the Department of Defense that the publication of products of fundamental research will remain unrestricted to the maximum extent possible" (DARPA-BAA-10-35 2010, DARPA-RA-10-76 2010). However, DARPA may change the research designation (and hence the disclosure provisions) after research has been completed at the discretion of the DARPA contracting officer according to this language:

> in those rare and exceptional circumstances where the applied research effort presents a high likelihood of disclosing performance characteristics of military systems or manufacturing technologies that are unique and critical to defense, and where agreement on restrictions have been recorded in the contract or grant. Such research is referred to by DARPA as "Restricted Research." (DARPA-BAA-10-35 2010, DARPA-RA-10-76 2010)

Depending on the designation imposed by the Contracting Officer, a variety of publication disclosure limits may be imposed (see table 1.1).

With regards to noncommercial and commercial technical data and computer software, as well as patents and other forms of intellectual property, disclosure and control is governed by the Defense Federal Acquisition Regulation Supplement (DFARS). However, rather than disclosure per se, the main concern of the funding agency lies in maintaining control rights over ideas. For procurement contracts, the proposer must identify all commercial and "noncommercial technical data and . . . computer software that it plans to generate, develop, and/or deliver under any proposed award instrument in which the Government will acquire less than unlimited rights, and to assert specific restrictions on those deliverables" (DARPA-BAA-10-35 2010). It is important to note that the government assumes unlimited rights to any technical data and software not delineated. Researchers who undertake nonprocurement contracts must disclose similar information, primarily restrictions on government use of technical data and software. Just as the NSF and NIH require that patent filings be documented, DARPA requires documentation proving "ownership of or possession of appropriate licens-

Table 1.1 US Department of Defense publication restrictions[a]

DoD distribution statement	Description
The statement below requires review through DISTAR	
A	Approved for public release; distribution is unlimited
The statements below are assigned by the sponsoring DARPA Program manager	
C	Distribution authorizes US government agencies and their contractors (fill in reason) (date of determination). Other requests for this document shall be referred to (insert DoD controlling office).
D	Distribution authorized to the Department of Defense and US DoD contractors only (fill in reason) (fill in date). Other requests for this document shall be referred to (insert DoD controlling office).
B	Distribution authorized to US government agencies only (fill in reason) (date of determination). Other requests for this document shall be referred to (insert DoD controlling office).
E	Distribution authorized to DoD components only (fill in reason) (date of determination). Other requests for this documents shall be referred to (insert DoD controlling office).
X	Distribution authorized to US government agencies and private individuals or enterprises eligible to obtain export-controlled technical data in accordance with DoD Directive 5230.25, Withholding Unclassified Technical Data from Public Disclosure (date of determination). DoD controlling office is (insert).
F	Further dissemination only as directed by (insert DoD controlling office) (date of determination) or higher DoD authority.

[a] DARPA Distribution Statements 2010

ing rights to all patented inventions (or inventions for which a patent application has been filed)" (DARPA-BAA-10-35 2010). In addition, DFARS 227.303 gives patent rights to the contractor for all inventions discovered while under contract. Thus, overall, DARPA's standard contractual obligations on disclosure are relatively unrestrictive with respect to intellectual property ownership and the dissemination of information.

1.3.3 Disclosure Practices of Private-Sector Funders

The disclosure practices of private-sector-funded research taking place within private-sector firms is beyond the scope of this chapter. However, of the $200 billion in private-sector funds spent on R&D, over $2 billion are spent on research taking place within US universities, which constitutes 5 percent of the university research budget. Private-sector funding is particularly widespread among life science researchers: A survey of more than two thousand life scientists at the fifty US universities receiving the most National Institutes of Health funding found that more than 25 percent of the most productive researchers received industry funding—over 36 percent in clinical departments compared to 21 percent in nonclinical departments (Blumenthal et al. 1996).

Table 1.2 **Commercial outcomes of research by life-science faculty members according to type of outcome**

	Outcome of research (Percent of respondents)						
Industrial support	Applied for patent	Patent issued	Patent licensed	Trade secret	Product under review	Product on market	New company
Yes	42.0	25.0	18.5	14.5	26.7	26.1	14.3
No	24.0	12.6	8.7	4.7	5.5	10.8	6.0

Note: $P < 0.001$ for all comparisons between the subgroup with industrial support and the subgroup without such support.

Source: Reproduced from Blumenthal et al. 1996, 1,737.

With regards to disclosure, industrial funders are more closely associated with attempts to enforce *secrecy* on the scientists they fund. The challenge of limiting secrecy falls to sponsored research administrators within universities as well as on academic scientists themselves. In current industry-funded medical science, for example, secrecy appears to be widespread. The precise disclosure requirements placed on recipients of industry funding are not systematically documented. However, several recent surveys of life science researchers found that faculty members with industrial support were significantly more likely than those without industrial support to report that their research had resulted in trade secrets (14.5 percent vs. 4.7 percent), thus suggesting more limited disclosure linked to industrial funding (this figure rises to over 17 percent for the subset of over 500 researchers whose area of focus is in biotechnology—including recombinant DNA, monoclonal antibodies, and gene sequencing; however, these researchers are also more likely to apply for patents and are more productive in publication terms as illustrated in table 1.2).

Concerns over delays in publication disclosure, while less concerning than secrecy, are still salient in research. As leading commentators have noted: "The enormous legal and financial power of the pharmaceutical industry puts clinical investigators in a very difficult position if there is a major controversy about the outcome of a particular study." (Nathan and Weatherall 2002). In several cases, scientists have accused their funders of attempting to limit disclosure, particularly of negative clinical results (Haack 2006), exemplifying the complex relationship between researchers, their funders, and the universities (and medical schools) who serve as the intermediaries in constructing and executing these contracts and in setting appropriate levels of disclosure.[32] As noted in a leading medical journal "[t]he intense pressure on individuals at academic institutions to publish and on the sponsoring

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[32] Kern, D., Crausman, R. S. Durand, K. T. Nayer, A. and Kuhn, C., III. Flock worker's lung: chronic interstitial lung disease in the nylon flocking industry. *Ann Intern Med* 1998;129:261–272. [Erratum, *Ann Intern Med* 1999;130:246.] Rennie D. Thyroid storm. *JAMA* 1997;277:1238–1243. [Erratum, *JAMA* 1997;277:1762.]

companies to get their drugs on the market sometimes produce[s] tensions between the two parties, and if results are not favorable, disagreements can develop[,] leading to disputes, innuendos, and even legal action."[33] More pragmatic is the voice from leading journal *Nature Biotechnology* that asks, "When is it reasonable for academics to expect total freedom over the data they have gathered on a company's behalf, especially if they have signed a confidentiality agreement?"[34]

The debate over privately funded medical research and, more broadly, regarding all industrial funding of academic research is grounded in the contracts that are signed between academic scientists and the private corporations who fund them. Certainly, scandals, such as those experienced in academic medical centers, have exacerbated the need for clearer rules. Early examples of industry-university contracts gave many of the rights to the knowledge produced (and its disclosure) to the funder (usually referred to as the sponsor). In the past decade, universities have become more sensitive to charges of "research-for-hire" and the possibility that knowledge is being withheld to serve corporate interests. However, while the Technology Transfer Office (TTO) function has received considerable attention among scholars of innovation and the academic-industry boundary (Owen-Smith 2005; Mowery et al. 2004), the ways in which universities contract over the incoming funding (rather than the outgoing licensing of completed projects) is poorly understood. We have little systematic knowledge of the disclosure provisions put into place for privately (commercially) sponsored research. To fill this gap, we have gathered some preliminary data in this regard to catalogue the contractual practices of twenty major US research universities.[35]

The contractual provisions shaping disclosure (and ownership) of industry-funded research in academia are rarely established via a bilateral agreement between researcher and funder. More typically, the negotiation is carried out and the contract signed by an "Office of Sponsored Projects," which seeks to represent the broader interests of the university in maintaining the disclosure of research findings. Our analysis focuses on the standard contractual terms offered to industrial sponsors in single-sponsor research agreements with regard to publications, rights to tangible research property, university project inventions, university copyrightable software and databases and university copyrightable works other than software. There

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[33] Donald M. Poretz, Letter to the Editor, Outcomes of a Trial of HIV-1 Immunogen in Patients with HIV Infection, 285 *JAMA* 2192, 2192–93 (2001).

[34] Editorial, Knee-Jerk Response, 18 *Nature Biotechnology* 1223 (2000)

[35] The twenty universities in alphabetical order are Dartmouth College, Carnegie Mellon University, Case Western Reserve University, Cornell University, Emory University, Georgia Tech, Harvard, Johns Hopkins University, Massachusetts Institute of Technology, Rochester Institute of Technology, Stanford, University of Arizona, University of California at Berkeley, University of Florida, University of Pennsylvania, University of Pittsburgh, University of Texas at Austin, University of Washington, University of Wisconsin, and Washington University.

appears to be significant heterogeneity among the terms surrounding publications and rights in tangible research property across universities, whereas the terms for university project inventions, university copyrightable works other than software, and university copyrightable software and databases are similar across the sample.

Publication

With regards to disclosure via publication, sixteen of the twenty universities in our sample explicitly address publication restrictions in single-sponsor research agreements with industrial entities including terms governing the public disclosure of information gained in research, the existence of prepublication sponsor review, the time for review (if permitted), exceptions in permitted reviews for theses or dissertations and sponsor acknowledgment.[36] We present Article VI of the research contract used by the University of California at Berkeley's Sponsored Projects Office (2011) as an example of common terms presented to corporate sponsors with regard to publications:

> ARTICLE VI. PUBLICATION California will have the right to copyright, publish, disclose, disseminate and use, in whole and in part, any data or information received or developed under this agreement. Copies of any proposed publication will be provided to Sponsor thirty (30) days prior to submission for Sponsor's review, comment, and identification of any of Sponsor's proprietary data which has inadvertently been included and which Sponsor wishes to have deleted. During this review period, Sponsor may also identify patentable inventions for which it wishes California to file for patent protection. In such case, California will delay publication up to an additional sixty (60) days in order to file such patent application.

The University of California at Berkeley and nine other universities in our sample permit the disclosure of all information that is not marked as confidential by the sponsor, five universities allow full disclosure, and the University of Texas at Austin has a more complex policy: it allows full disclosure if it has exclusive rights to the intellectual property produced in the project, but it gives the sponsor the right to mark information as confidential and nonpublishable if the sponsor has some claim to the intellectual property produced. Nonetheless, every university permits presponsor publication review, even though the sponsor may not necessarily have rights to restrict the information divulged in the publication. A majority of universities give the sponsor thirty days for review and allow between a thirty-day and sixty-day extension. However, some universities gave more favorable terms, such as a 180-day extension and even a three-month standard review with a three-

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[36] The four universities that did not address publication restrictions are the University of Arizona, University of Washington, University of Wisconsin, and Washington University.

month extension. This heterogeneity across universities is surprising and merits further investigation into its causes and effects.

Patenting

While the terms surrounding publications are heterogeneous across universities, the terms governing rights in tangible research property are dichotomous.[37] When addressed, the university is always given the right to use all tangible research property. Ownership rights generally require further negotiation and/or separate agreement. Harvard is the only university we examined that claims ownership rights over the research property and only gives the sponsor rights for internal research use. While firm conclusions cannot be drawn from such a small sample, it appears that the dichotomy presented in the terms governing rights in tangible research property are a result of the fact that universities must often enter into negotiations and/or use a separate agreement beyond the boilerplate contract when assigning these rights.

Unlike the terms for publications and rights in tangible research property, many of the terms governing university inventions are nearly uniform across the eleven universities, including: which party is awarded ownership of inventions, whether internal research licenses are offered to the nonowning party, the existence and nature of any commercial licenses, the amount of time given to elect to license (if available), the amount of time given to negotiate collective licenses, and whether the sponsor must reimburse expenses. We present an excerpt from Section 11 of the research agreement used by the Massachusetts Institute of Technology's Office of Sponsored Programs (2011) as an example of common terms presented to industrial sponsors with regard to inventions:

> A. MIT INVENTIONS. MIT shall have sole title to (i) any invention conceived or first reduced to practice solely by employees and/or students of MIT in the performance of the Research (each an "MIT Invention") and (ii) any invention conceived or first reduced to practice by employees of the Sponsor with significant use of funds or facilities administered by MIT, if the invention is conceived or reduced to practice other than in the performance of the Research. The Sponsor shall be notified of any MIT Invention promptly after a disclosure is received by MIT's Technology Licensing Office. MIT may (a) file a patent application at its own discretion or (b) shall do so at the request of the Sponsor and at the Sponsor's expense.
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> B. LICENSING OPTIONS. For each MIT Invention on which a patent application is filed by MIT, MIT hereby grants the Sponsor a non-exclusive,

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[37] The eleven universities in alphabetical order are Georgia Tech, Harvard, Johns Hopkins University, Massachusetts Institute of Technology, Stanford, University of Arizona, University of California at Berkeley, University of Texas at Austin, University of Washington, University of Wisconsin, and Washington University.

> non-transferable, royalty-free license for internal research purposes. The Sponsor shall further be entitled to elect one of the following alternatives by notice in writing to MIT within six (6) months after MIT's notification to the Sponsor that a patent application has been filed:
>
> 1. a non-exclusive, non-transferable, world-wide, royalty-free license (in a designated field of use, where appropriate) to the Sponsor, without the right to sublicense, in the United States and/or any foreign country elected by the Sponsor pursuant to Section 11.C. below, to make, have made, use, lease, sell and import products embodying or produced through the use of such invention, provided that the Sponsor agrees to (a) demonstrate reasonable efforts to commercialize the technology in the public interest, (b) reimburse MIT for the costs of patent prosecution and maintenance in the United States and any elected foreign country, and (c) indemnify MIT for any liability arising from Company's use or sale of the invention; or
> 2. a royalty-bearing, limited-term, exclusive license (subject to third party rights, if any, and in a designated field of use, where appropriate) to the Sponsor, including the right to sublicense, in the United States and/or any foreign country elected by the Sponsor pursuant to Section 11.C. below, to make, have made, use, lease, sell and import products embodying or produced through the use of such invention, provided that this option to elect an exclusive license is (a) subject to MIT's concurrence and the negotiation of commercially reasonable terms and conditions and (b) conditioned upon Sponsor's agreement to reimburse MIT for the costs of patent prosecution and maintenance in the United States and any elected foreign country and to cause any products produced pursuant to this license that will be used or sold in the United States to be substantially manufactured in the United States.
>
> If the Sponsor and MIT do not enter into a license agreement within three (3) months after Sponsor's election to proceed under paragraph 11.B.1. or 11.B.2. above, the Sponsor's rights under paragraphs 11.B.1. and 11.B.2. will expire.

As observed in MIT's agreement, the university retains ownership of all project inventions in each case and can therefore disclose the knowledge via patent filing. In addition, almost all universities examined automatically offer the sponsor a license for internal research use and none explicitly deny such a license. With regard to commercial licenses, the terms range from an option to negotiate a nonexclusive royalty-free license (NERF) to giving a royalty-bearing sublicense will contract. However, the majority of universities offer both nonsublicensable NERFs and royalty-bearing sublicensable contracts. Harvard is the only outlier, offering a NERF for blocking intellectual property, which is sublicensable if the license for dominating intellectual property is also granted, and options for royalty-bearing licenses that are either exclusive and sublicensable or nonexclusive and nonsublicensable. As with university project inventions, the terms governing the ownership and licensing of copyrightable software and databases are consistent across the ten universities we examined.[38]

Taken together, the university-industry contracts suggest that the nature of the disclosure terms that prevail when university academics seek out private-sector funding are more complex than those used under conditions of public-sector federal funding. We have been led to believe in our informal conversations with university Offices of Sponsored Research that in recent years public funding coming from philanthropic sources is increasingly the subject of more stringent disclosure conditions. Rather than attempting to limit disclosure and enable secrecy (albeit time limited), philanthropic foundations are hoping to force more rapid disclosure by shifting the burden on publication from a norm or expectation toward a requirement. Likewise, they hope to shift ownership or licensing terms related to patents in a way that ensures that commercial rights still enable the development of useful products and services for underserved communities and nations (Furman, Murray, and Stern 2010). These trends, which deserve further scrutiny, highlight the critical role of disclosure requirements in shaping scientists' preferences for funding from different sources.

In the model that follows, we combine our understanding of both the selection and disclosure requirements of funds and their interaction with scientists' preferences to offer a window into the role of public versus private funding of R&D in academia.

1.4 Selection, Commercialization, and Disclosure in a Model of Private-Public Funding

The two previous sections illustrated the selection intentions as well as the conditions that public funders place on the disclosure and commercialization of research. For example, funders usually select projects on the basis of scientific merit rather than capacity for immediate application. In addition, for the most part, funders do not explicitly consider whether other sources of funding might be forthcoming for projects within their selection set. Nonetheless, funders do display an active concern about what might become of the outcomes of research projects. They often impose disclosure requirements—through publication and other means—and can also limit commercialization options.

In this section, we provide a model of private and public funding of scientific projects and the ways in which funding criteria (both in selection and disclosure) made by these types of funders interact and shape the portfolio of funded projects. This modeling approach allows us to examine whether

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[38] Harvard's standard research agreement does not address copyrightable works.

and how funding conditions impact the number, mix, and openness of projects that are funded. We see this theoretical exercise as a critical first step toward identifying the first-order trade-offs that arise when publicly funded projects interact with privately funded ones. This will provide a basis for hypotheses that may be tested empirically in the future, as well as important considerations in identifying the causal impact of changes in funding policy (such as those that arose as a result of the Bayh-Dole Act).

To this end, the focus of our model is on the public funder's conditions regarding commercialization and patenting rather than on selection and disclosure per se (although those conditions have important consequences for these). With regard to selection, we assume that it is difficult for the funder to observe immediate applicability, while it can more readily evaluate scientific merit. We do, however, discuss what happens when funders can observe aspects beyond pure scientific merit. With regard to disclosure, the aforementioned evidence suggests that we can take as a given that disclosure rights are preserved and, indeed, compelled as a condition for the receipt of public funds. We will demonstrate that this requirement, however, has an important impact on the decisions of scientists and potential commercial funders to accept such funds.

1.4.1 Key Assumptions and Setup

We assume that there is a $[0,1] \times [0,1]$ space of research projects that can potentially be funded. The cost of funding each project is a constant amount, k. Projects also require a scientist to perform the research.[39] Projects differ in terms of their potential immediate social benefit, v, and their potential present value of future scientific benefits, b. The b and v are independently and identically distributed, uniformly on $[0,1]$.[40]

For a project with potential benefits (b, v) there are constraints on realizing this scientific and social value. With regard to immediate social (and economic) value, v is realized if the results of the research project are commercialized by competitive firms; otherwise, a fraction of the value, δ, is lost under monopoly production. We assume that competition can be fully provided by two firms who each capture β of immediate value while a monopolist captures a fraction $\mu \in [2\beta, 1-\delta]$.

With regard to scientific benefit, b is realized if, and only if, research outcomes are publicly disclosed (i.e., the scientist engages in disclosure via publishing). Otherwise, there are no scientific benefits. It is assumed that the scientist appropriates b in "kudos" if the project proceeds and its results are disclosed in a scientific publication.

Taken together, these conditions assure that maximum social value is realized if there is both competitive commercialization and scientific publication

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[39] It is assumed that scientists are suitable for, at most, one potential project.

[40] We examine the consequences of nonindependence of b and v later.

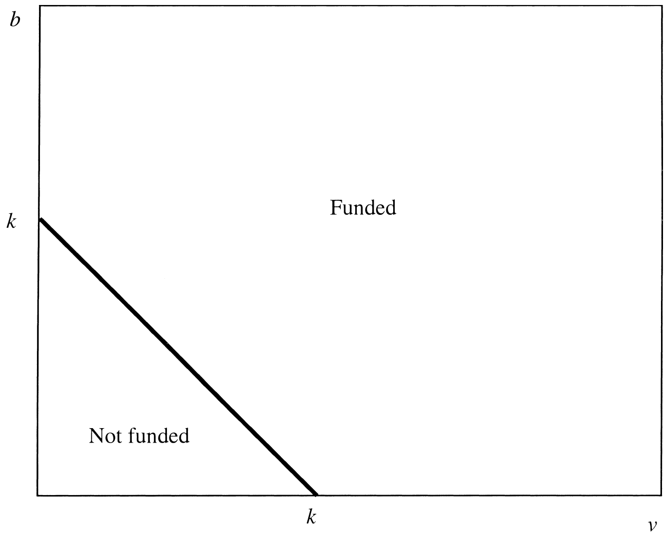

Fig. 1.5 Optimal funding

under conditions where all projects for which $v + b \geq k$ are funded while those with $v + b < k$ do not proceed (figure 1.5).

1.4.2 Intellectual Property and Competition

For simplicity, we assume that at most two firms can commercialize the outcome of a given research project.[41] Commercialization of a project carries no cost for the firm who funds a project but a cost, θ, for a rival firm engaging in parallel commercialization. This cost is distributed uniformly on [0,1]. However, if there is a publication, these costs are reduced by a fixed amount, $d < 1 - \beta v$.[42]

If permitted by the funder, the research outcome from a project may include a patent that is conferred on one firm. The existence of a patent generates a probability that entry may be blocked. There are many ways this might be modeled. Here we assume that, if there is a patent, then with probability $1 - \rho$, entry is possible; otherwise, it is not. Specifically, if not blocked by a patent, an entrant will only enter if $\beta v + d \geq \theta$ if there is a publication or $\beta v \geq \theta$, if there is not. This means that, if a firm controls the intellectual property of a research project, its expected profits are

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[41] If more firms can commercialize the research, then this only intensifies the gap between competition and monopoly in terms of profits and social value.

[42] Later we consider what happens if commercialization requires the scientist's cooperation to transfer key knowledge (other than that done through publication). This will raise the possibility that commercialization is not a certain outcome when the scientist does not have a commercial interest.

$\mu v - (1 - \rho)(\beta v + d)(\mu - \beta)v$ if there is disclosure of scientific knowledge and $\mu v - (1 - \rho)\beta v(\mu - \beta)v$ otherwise.[43] In what follows, we use a variable, i, to indicate whether a firm as a patent ($i = 1$) or not ($i = 0$).

1.4.3 Scientist-Firm Negotiations

Firms provide the project capital, while scientists provide the labor. In this model, it is clear that while scientists may benefit from publication, firms do not.[44] However, publication may increase joint surplus if $b > (1 - i\rho)d(\mu - \beta)v$. In this case, if profits are still nonnegative, a firm would find it profit maximizing to allow publication, as this would allow them to reduce payments to the scientist to ensure they participated in the project (Stern 2004).

For many projects, there will be a surplus (or rents) created. The division of the surplus is determined by the relative bargaining power of scientists and firms. In Gans, Murray, and Stern (2010), negotiations over whether to disclose research results are modeled using a Nash bargaining solution with arbitrary bargaining power. Here, for expositional ease, it is assumed that scientists have all of the bargaining power. Specifically, it is assumed that the private supply of capital is perfectly elastic and consequently, firms will receive enough surplus (net of payments to scientists or license fees to scientist employers) to ensure that profits cover their capital costs.

1.4.4 Pure Private Funding

We begin by examining outcomes when only private funding is available. In this case, there will be no constraints placed on the ability to patent or earn commercial returns. However, disclosures through publication may still arise if this raises total surplus generated by the research project.

It is useful to define the threshold values of v that will allow a project to be commercially viable; that is, how high does v have to be to ensure that the commercial profits cover capital costs? This defines the set of projects capable of commercial funding and in the case the only projects funded in a regime of pure private funding. First, we define $\underline{v}$ as the minimum level of immediate value that would allow the net profits from any project with $v \geq \underline{v}$ to cover capital costs. That is,

$$\mu\underline{v} - (1 - \rho)\beta\underline{v}(\mu - \beta)\underline{v} = k. \tag{1}$$

Second, we define $\underline{v}_{d,1}$ as the minimum level of immediate value that would allow the net profits from any project with publication and a patent and with $v \geq \underline{v}_{d,1}$ to cover capital costs. That is,

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[43] Note that it is always profit maximizing for the firm to choose to patent if it is permitted to do so. In reality, patents have their own disclosure requirements and other transactional costs that may make this decision more nuanced.

[44] This is an extreme assumption. Firms may benefit from funding in terms of marketing benefits, attracting talent, reputation and also defensive publishing to influence patent race outcomes.

$$\mu \underline{v}_{d,1} - (1 - \rho)(\beta \underline{v}_{d,1} + d)(\mu - \beta)\underline{v}_{d,1} = k. \tag{2}$$

Third, we define $\underline{v}_{d,0}$ as the minimum level of immediate value that would allow the net profits from any project with publication but no patent and with $v \geq \underline{v}_{d,0}$ to cover capital costs. That is,

$$\mu \underline{v}_{d,0} - (\beta \underline{v}_{d,0} + d)(\mu - \beta)\underline{v}_{d,0} = k. \tag{3}$$

Note that $\underline{v} < \underline{v}_{d,1} < \underline{v}_{d,0}$ as a publication diminishes commercial returns. This implies that all projects with $v \geq \underline{v}$ will be funded. This is because, even without publication, the profits from those projects will enable the project to cover capital and scientist costs.

The following proposition characterizes the equilibrium outcomes:

PROPOSITION 1. *A research project* (b, v) *is privately funded with no publication if* $v \geq \underline{v}$ *and (i)* $b < d(1 - \rho)(\mu - \beta)v$ *or (ii)* $b \geq d(1 - \rho)(\mu - \beta)v$ *and* $v < \underline{v}_{d,1}$. *A research project* (b, v) *is privately funded with publication if and only if* $b \geq d(1 - \rho)(\mu - \beta)v$ *and* $v \geq \underline{v}_{d,1}$.

The proof involves a straightforward comparison of the conditions that maximize total surplus. Figure 1.6 depicts the equilibrium outcome. Importantly, projects that have both a high future and immediate value are more likely to be funded and are also more likely to be disclosed through publication. These projects lie squarely in Pasteur's Quadrant. Because the scientist is liquidity constrained, some projects whereby $b \geq d(1 - \rho)(\mu - \beta)v$ are funded but do not involve a publication.

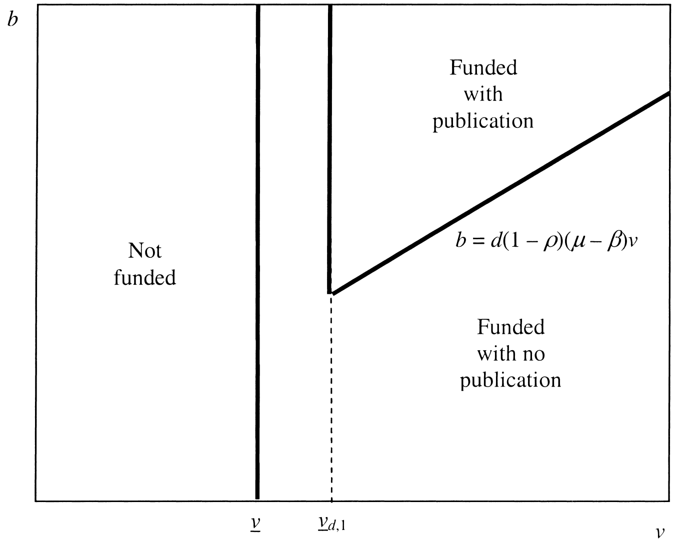

Fig. 1.6 Pure private funding

At this point, it is useful to note the impact of stronger intellectual property protection, as measured by ρ, on the equilibrium outcome. Notice that an increase in ρ will increase both $\underline{v}$ and $\underline{v}_{d,1}$ but will also impact on the margin between publishing and not. The former comparative static comes from the pure increment to commercial returns accompanying stronger patent protection. The latter arises because stronger patents protect the firm from the consequences of published disclosure, thereby reducing the costs of such disclosure. This means that more projects will be funded and, in addition, a larger number of projects will be funded that permit publication. As Gans, Murray, and Stern (2010) demonstrate, this is not a consequence of scientists having all of the bargaining power and can arise simply because firms wish to economize on scientist labor costs.

1.4.5 Public Funding

We now turn to examine what happens to the mix and disclosure of projects when there is a public funder who is interested in providing maximizing social value ($b + v$). Under these conditions, we assume that the public funder is constrained in its ability to assess and consequently select projects for funding. Specifically, we assume that the public funder can only observe b and cannot observe v. The idea is that b is something that is subject to possible peer review in such a way that it can be properly assessed, whereas v is somewhat harder to extract as information from the marketplace. Maurer and Scotchmer (2004) tie this specifically to published outputs that can serve as a signal of scientific value being met and also likely to be met in the future through a reputational mechanism. We later examine what happens when more symmetric information acquisition across project dimensions is possible.

The public funder is assumed to be liquidity constrained (in contrast to private funders). It has total funds available of K ($< k$) so it can only fund at most K/k projects. This implies that there exists some threshold, $\underline{b}$, such that it would fund all proposals with $b > \underline{b}$.[45] Note that, as some projects satisfying this constraint may choose not to apply for public funding but be purely privately funded, $\underline{b}$ depends on the equilibrium outcome in terms of each project's opt-in decisions.

The key focus of our analysis is on the restrictions the public funder attaches to funds received. One obvious restriction is a requirement to publish without which future value cannot be generated. Consequently, it will

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[45] It is possible that the funder could also have a maximum cut off that did not fund projects with very high scientific value. This might arise if many such projects would be funded anyway and so the funder was willing to sacrifice not funding those with high scientific value that would not otherwise be funded. As this possibility does not fit the description of any known funding agency, we implicitly assume that is not the case here. However, strictly speaking this would only apply under certain distributional assumptions on the space of projects as well as the availability of public funds.

be assumed throughout that the public funder always requires this in return for accepting any funds.

The other restrictions we consider are as follows: First, the scientist cannot profit from commercialization, and no patent can be applied for and granted. This is a common requirement from funding by government sources. Second, the scientist can profit from commercialization, but patenting is not permitted. Finally, that there are no commercialization restrictions and patenting is permitted without any conditions on how patent rights are used. We examine each in turn.

No Commercial Payments or Patent

When scientists (or their institutions) cannot receive commercial payments, their decision as to whether to accept public funding (if offered) will compare the kudos they receive, b, with the potential surplus otherwise.

PROPOSITION 2. *When public funding prohibits commercial payments to the scientist, such funding will only be accepted by a research project* (b, v) *if:*

(i) $v < \underline{v}$; *or*

(ii) $v \in \{\underline{v}, \underline{v}_{d,1}\}$ *and* $b \geq \mu v - (1 - \rho)\beta v(\mu - \beta)v - k$.

A research project (b, v) *will be privately funded with publication if* $v \geq \underline{v}_{d,1}$ *and* $b > d(1 - \rho)(\mu - \beta)v$. *A research project* (b, v) *will be privately funded without publication if* $v \geq \underline{v}$ *and* $b < \mu v - (1 - \rho)\beta v(\mu - \beta)v - k$.

The proof is straightforward once it is noted that:

$$\mu v - (1 - \rho)\beta v(\mu - \beta)v - k > (1 - \rho)d(\mu - \beta)v \Leftrightarrow v > \underline{v}_{d,1}.$$

A possible outcome is depicted in figure 1.7. There are three things of interest. First, if a project was privately funded with publication prior to the existence of a public funder, it remains privately funded. This is because the scientist can earn profits as well as kudos with private funding. Second, public funding does crowd out some private funding but where it does so it generates a publication. Thus, more projects are funded and overall openness has increased compared to a purely private system. Finally, there may be projects the public funder would like to fund in order to generate scientific benefits from publication, but these projects remain privately funded and unpublished. This is because the funding conditions restricting commercial payment cause too many projects to opt out of receiving public funding.

Interestingly, in this regime, the total level of public funding available has no impact on whether projects with $v \geq \underline{v}_{d,1}$ are funded and what type of funding those projects would receive; those projects remain private. That is, *the addition of public funding with restrictions on profiting from commercialization and patenting does not change the set of privately funded projects that are disclosed.*

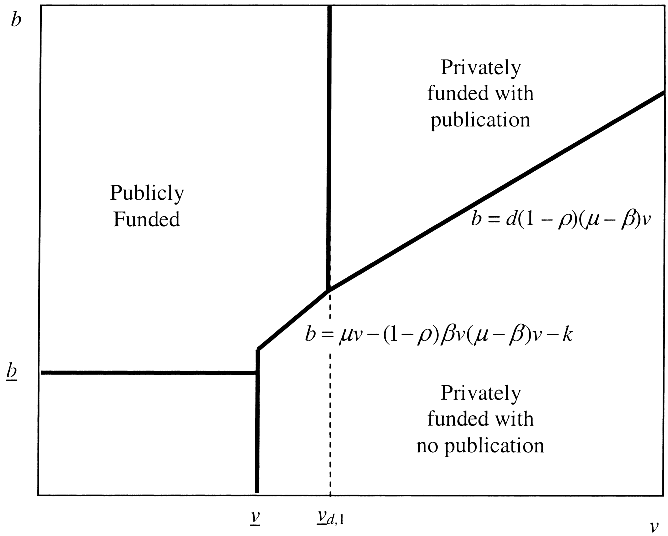

Fig. 1.7 Public funding (no commerce/no patent)

Commercial Payment but No Patent

Suppose now that the scientist is permitted to have a commercial interest in the project, but if it accepts public funds, no patent can be taken out. Consequently, imitative entry can proceed in an uninhibited manner.[46] The following proposition summarizes the resulting equilibrium:

PROPOSITION 3. *When public funding prohibits patenting, such funding will only be accepted by a research project (b, v) if:*

(*i*) $v < \underline{v}$*; or*

(*ii*) $v \in \left\{ \underline{v}, \frac{1}{2\beta}\left(\sqrt{d^2 + \frac{4k\beta}{(\mu-\beta)\rho}} - d\right)\right\}$ *and* $b \geq (\rho\beta v + d)(\mu - \beta)v - k$.

A research project (b, v) *will be privately funded with publication if* $v \geq (1/[2\beta])(\{d^2 + [4k\beta/(\mu - \beta)\rho]\}^{1/2} - d)$ *and* $b > d(1 - \rho)(\mu - \beta)v$*. A research project* (b, v) *will be privately funded without publication if* $v \geq \underline{v}$ *and* $b < (\rho\beta v + d)(\mu - \beta)v - k$*.*

The proof follows from that fact that:

$$(\rho\beta v + d)(\mu - \beta)v - k > (1 - \rho)d(\mu - \beta)v \Leftrightarrow v > \frac{1}{2\beta}\left(\sqrt{d^2 + \frac{4k\beta}{(\mu-\beta)\rho}} - d\right).$$

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[46] In addition, no license revenue can be generated; something we discuss later.

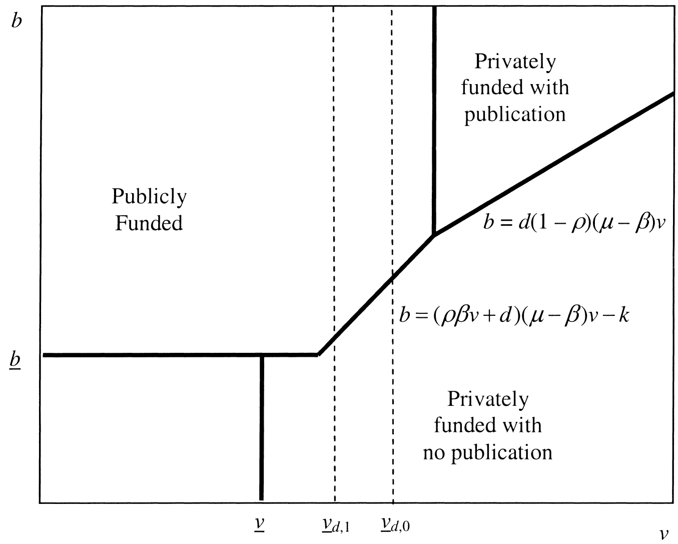

Fig. 1.8 Public funding (commerce/no patent)

A possible outcome is depicted in figure 1.8. In comparison to the no commercial payment case, observe first that there is more crowding out of privately funded projects and consequently, the total number of projects funded falls. This means that the marginal project receiving public funding has a higher b. Moreover, some of those projects crowded out are those that received private funding but involved disclosure. Nonetheless, some additional projects are disclosed. These projects, however, are of relatively low b (our proxy for scientific and potential future value). Finally, the additional projects receiving public funding have a higher chance of resulting in competition and so the realized immediate value for those projects is likely to be higher.

It is useful to compare this outcome to a weaker restriction—that a patent can be taken out, but it should be licensed openly, as proposed in Furman, Murray, and Stern (2010) and elsewhere. The idea here is to increase the probability that there is competition and that the immediate value of the innovation is socially realized. The question is whether this actually adds value to the firm relative to the no patent case.

If a patent is licensed to rivals, this allows the firm to earn more revenue in the event such rivals should enter. Indeed, if there were no restrictions on the fee that could be offered to a potential competitor, the firm could appropriate all of the competitor's profits; that is, $\beta v + d - \theta$ (assuming the fixed cost is realized and observable prior to license negotiations taking place). In that case, the firm's expected profits from accepting public funding become $\mu v - (\beta v + d)((\mu - v)v - 1/2(\beta v + d))$. This makes it more likely that the firm would accept public funding but significantly makes the firm less concerned about the impact of disclosure requirements on its profits.

Of course, this assumes that the firm can charge a lump-sum license fee but not otherwise control ex post competition through a license agreement; for example, by setting a license fee that preserves monopoly. A public funder would unlikely find much value in open licensing if it did not increase realized social value.

In addition, open licensing could give rivals a significant degree of bargaining power; especially if the onus was on the patent holder to ensure that licensing takes place. In this case, the fee may end up being close to some minimum amount as required by the funder and the outcomes may not be very different from the case where a patent is simply prohibited.

No Restrictions

Finally, we consider what happens when the public funder places no restrictions on how the research project might be commercialized. Previously, public funding may not be accepted because of a desire to appropriate commercial profits and take out a patent. In this case, the only restriction is that the project outcome has to be published. If $b < d(1 - \rho)(\mu - \beta)v - k$, this may result in a project choosing to opt out of public funding. Otherwise, such funding will be accepted if it is available. Figure 1.9 depicts a possible outcome.

The first thing to note is that every project that might have been privately funded with publication will opt to take out public funds if they are available.

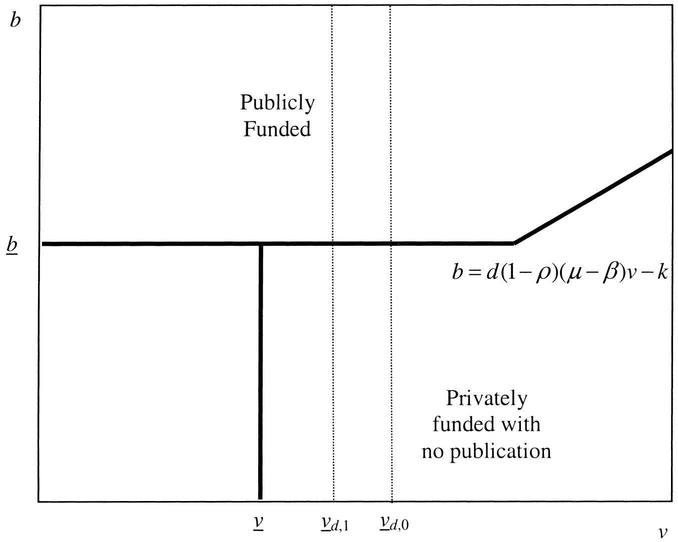

Fig. 1.9 Public funding (no restrictions)

Compared to the situation where the public funder allowed a commercial interest but no patent, this is a pure crowding out effect, with no benefits in terms of disclosure or increase in likely competition. Second, there are some privately funded projects without publication that do not receive public funding. However, there are also those for which the reverse might be the case. However, these are of lower *b* and hence, the shift in publications is socially more valuable.

1.4.6 Impact of the Bayh-Dole Act

This analysis gives some insight into the possible impact of the Bayh-Dole Act of 1980. That legislation removed restrictions on the patenting of government-funded research performed within universities. While it is not necessarily the case that scientists themselves appropriated commercial returns in the period that followed, their employers did, with a likely sharing of benefits in nonmonetary form. Thus, it was akin to a move from the no commercial interest, no patent case to the no restriction case.

The likely impact of the Act was, first, to have caused projects that might otherwise have been privately funded to become publicly funded. Moreover, the analysis demonstrates that this may not necessarily increase the degree of openness by the same amount, as many of the high scientific value projects would likely have been disclosed anyway.

There is little evidence that the Bayh-Dole Act had a significant impact on the number of research projects funded and performed within universities (Mowery and Sampat 2001) or on the mix of those projects (Mowery and Ziedonis 2002). While there was an increase in patenting, there is evidence that this was stimulated by other factors and, in fact, the quality of the patents was, on average, lower than prior to 1980 (Henderson, Jaffe, and Trajtenberg 1998).

Our analysis here is consistent with empirical findings that the quality of patented research from universities was reduced by the Bayh-Dole Act. Note that the marginal projects both encouraged and now patented as a result of the change in funding conditions are all at the lower end in terms of commercial prospects—arguably, the measure of quality associated with patent citation rates. Consequently, our model predicts precisely the decline in average quality that was observed empirically. Nonetheless, our analysis also identifies the broader role of university-based researchers in private innovative efforts as being relevant to consider when evaluating the full impact of the Bayh-Dole Act. To our knowledge, no such evaluation has yet been conducted.

Interdependence between Immediate Value and Scientific Merit

So far, we have assumed that *b* and *v* are independently distributed. What happens if they are interdependent? Specifically, how does this change the importance of imposing funding conditions on crowding out of private funding? If *b* and *v* are negatively correlated, then even in the absence of funding restrictions, very few high *b* projects would be available to opt for public funding and consequently, the crowding out effect will be lower. In this case, funders can more freely offer funding without restrictions. On the other hand, positive correlation of *b* and *v* implies that the reverse is true. In this case, public funders will want to be more diligent regarding conditions on commercialization and patenting to minimize crowding out.

What if Scientists Receive Kudos for Obtaining Grants?

In the previous analysis, scientists care about two things—kudos from publication and potential earnings from commercialization. In many higher education institutions, scientists also receive prestige from obtaining grants from public funders. The model here demonstrates that such prestige is likely to have negative consequences. In particular, it means that scientists may opt for public funding even in cases where they might have been able to privately fund projects with publication. This increases the crowding out effect, even in situations where public funders impose many restrictions on commercialization and patenting. The clear implication is that when crowding out is an issue, prestige associated with obtaining grants has negative consequences. Practically, however, it is difficult to separate out the prestige associated with grant awards, especially competitive grant awards, with the kudos likely to be generated from the outcomes of such grants.

Scientist Effort in Commercialization

Of course, expanding the funding base and assisting openness were not the primary rationales behind the Bayh-Dole Act. Instead, it was to unlock university research for commercialization by giving universities the ability to clarify commercial ownership and an obligation to facilitate commercialization and appropriate commercial returns. The idea behind this is quite consistent with economic theory: in the absence of a commercial stake, universities and academics would not expend much energy in trying to find commercial partners and communicate their innovations and research outcomes widely. Indeed, there is evidence that the Bayh-Dole Act did stimulate university level activities in technology transfer (Mowery and Ziedonis 2002).

In other words, when comparing a no commercial payment situation to a pure privately funded situation, some research projects would accept public funds but at the same time be commercialized at a lower rate than they would have been if they had been privately funded. As we move to a situation where public funding is granted unconditionally, then projects that receive some funding are more likely to be commercialized. This may include some low *v* projects. However, selection again plays a role. If we expect that it is high *v* projects that are more likely to be commercialized, we can also observe that those projects would have likely received private funding prior to the

Bayh-Dole Act. Thus, mere observations that more projects are being commercialized after 1980 may mask the true impact of the Bayh-Dole Act on commercialization—which is likely to be lower. This suggests considerable caution in the interpretation of such results.

The other implication is that proposals to improve the transactional efficiency of the commercialization process should receive additional attention, as these will impact on university-based research across the board. Kenney and Patton (2009) argue that ownership of patents should be vested with scientists, and Litan, Mitchell, and Reedy (2007) argue that universities should not have an exclusive option on commercializing research that is federally funded but performed in their home institutions. Instead, each emphasizes the role of competition in promoting more efficient search and commercialization from Universities.

Placing Weight on Immediate Value in Selection

So far, we have assumed that the public funder can only observe the future value of a research project and not its immediate value. Consequently, it could only use future value as a selection criterion. However, if the funder could also observe immediate application value, then it could reject funding of projects that had both high scientific and immediate value and could allocate those funds to other projects. Thus, perfect information would allow the funder—even operating alongside a private system—to more closely approximate the socially optimal outcome. As noted earlier, there was a sense in which the Gates Foundation undertook this practice by emphasizing projects of immediate value that, for some reason, were subject to difficulties in private appropriability that limited their ability to attract private funding.

More realistic is the possibility that public funders could use more sophisticated mechanisms to reveal whether a project would otherwise be of high immediate value. For example, Maurer and Scotchmer (2004) argue that matching funds assist public funders in selecting projects with high social prospects and not those with low prospects. They argue that a pure capital subsidy means that public funders may end up funding some low value projects. Instead, suppose that all projects required a minimum capital contribution from private funders before receiving an additional subsidy. In that situation, for projects with low social value, the minimum capital contribution screens them out, as even with the subsidy such projects will not earn a return for their private backers.

Here, the concern is with projects that might otherwise have received private funding and not require public funds. In this case, minimum capital requirements would not screen out those projects. Instead, matching funds could be tied to funding conditions. For instance, restricted grants that prevented commercialization or patenting might receive the full capital costs whereas unrestricted grants may only receive partial funding. Of course, these latter grants would still require disclosure through publication. In this

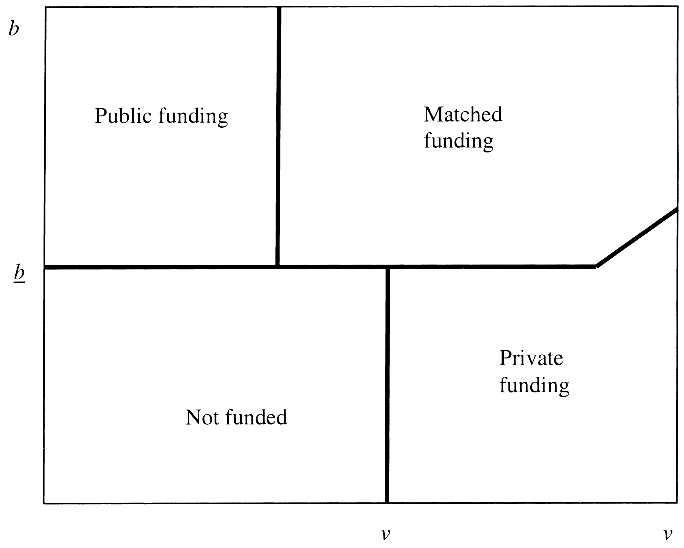

Fig. 1.10 Mixed funding rules

case, public funders would offer researchers a menu of options. A possible outcome of this is depicted in figure 1.10.

In figure 1.10, note that some projects choose open science with full public funding rather than the matching grant option. Note also that the matching grant makes public funding more attractive to some projects that switch from no publication to publication. However, it is clear that this outcome is superior for the public funder compared with the unrestricted funding case, as more projects receive funding and high scientific merit but low commercial return projects operate under open science. This suggests a rationale for tying a lack of restrictions on patenting and commercial exploitation of research with shared capital contributions for that research.

This mixed system overcomes some of the difficulties identified with matching grant systems. That occurs here, but by also providing restricted funding without matching grants, those projects with high scientific merit can be funded regardless.

1.5 Discussion and Agenda for Research

The design of research contracts by public or publicly spirited funders is an issue that has been understudied. Some prior formal models have examined the role of funding conditions on individual projects and their performance. Most notably, Aghion, Dewatripont, and Stein (2009) examine the interplay between an academic's choice of project (which comes with public funding) and ceding that right to private commercial interests. Their concern was that research effort be optimally allocated between exploration and exploitation of promising paths (see also Banal-Estañol and Macho-Stadler 2010). Importantly, they emphasized the importance of conditions (to select research direction) attached to public funding and contrasted these with conditions that would be imposed by private funders. With regard to openness, Mukherjee and Stern (2009) and Gans, Murray, and Stern (2010) examined the disclosure rights afforded research scientists. None of these investigations, however, analyzed how public funding conditions affect the mix of private-public projects and with it the level of disclosures across the whole system.

Our approach, in contrast, allows us to explore several of the more contentious issues associated with research funding. Specifically, we shed light on the arguments of some scholars who, noting the variability in the amount of profit that can be appropriated from inventive activity (see Romer 1990; Maurer and Scotchmer 2004), raise concerns that private funding may be concentrated among highly appropriable projects. Others claim that blanket public support may also fail to select the most socially valuable projects, and more sophisticated mechanisms should be employed to screen projects and also to ensure quality.

This chapter highlights a number of critical trade-offs that public funders must confront when supporting research projects. Our chief finding is a surprising one; even in the absence of public funding, many projects with high scientific merit and immediate applications will indeed be funded and, in fact, disclosed in an open manner. Public support, offered with conditions attached that shape commercialization (e.g., patents), will not be attractive to projects that are commercially valuable, and so a natural screen occurs. However, unrestricted public funds will ensure that those projects will take public funding thus leading to fewer projects funded overall without consequent gains in openness. This has implications as to the way funding organizations should think about the conditions they impose. Even where their support is directed toward projects with high scientific value, the funder's choice of disclosure requirements and commercialization restrictions affect the portfolio of projects that will be attracted by the support. Research scientists often have a range of funding choices, including private sector support, and this contours the final set of projects available to and selected by the public sector. Specifically, we noted that while lifting commercialization restrictions may increase the number of projects with immediate application to seek public funds, this comes at the expense of projects that might both have been privately funded and, in even in that environment, generated high levels of disclosure. The end result may be a significant crowding out effect, with limited gains in terms of the quality of scientific discourse and disclosure.

Supporting this notion, we observed that, while public funding organizations have paid attention to the impact of funding conditions on the outcomes of specific projects they fund, very little attention is paid to broader outcomes on the innovation system per se. Our survey notes that selection criteria tend to have common claims based on measurable scientific outcomes across funding organizations but are less explicit in their acknowledgement of wider impacts. In contrast, the growing not-for-profit foundation sector, in an attempt to differentiate themselves from purely public funders, has increased their emphasis on social impact. The broad implications of this transformation are not yet understood, nor do we have the systematic information we need to assess the influence of foundations on the public-private R&D complex. We noted also that disclosure requirements, while acknowledged, were not necessarily a key condition of funding, although they may play a role in reputational mechanisms to ensure future grants. This trend is changing in the context of foundations that are also becoming more aggressive regarding their disclosure and commercialization conditions but work within a limited framework of analysis in enforcing these requirements. Finally, we observed that commercialization outcomes have been considered with explicit concern for conflicts of interest as well as their effects in facilitating the diffusion of scientific ideas. However, little attention has been paid to whether these restrictions have adversely affected the distribution of public funds or generated real improvements overall in the openness in science.

These concerns suggest the need for future research to understand these trade-offs. In our opinion, future research should be directed at the following questions:

1. How do *stated* selection and disclosure criteria translate into *realized* selection and disclosure outcomes? There is a need to examine the mix of projects actually funded by public organizations and to see where, in fact, they lie along the scientific merit/immediate application space as identified by Stokes (1997). In addition, are there indeed systematic differences in the level of disclosure achieved in this space conditioned on the source of funding (private vs. public)?
2. Do changes in commercialization opportunities affect the mix of projects funded and their level of disclosure? Taking, for example, the Bayh-Dole Act as an experiment, what was the impact of this reform on the mix of projects claiming public funds? Did projects that might have otherwise been privately funded end up involving higher levels of disclosure through academic routes?
3. How do scientists actually match their desired research projects to particular funding sources? Our model has identified the key role that scientists play in shaping the demand for research funding associated with different terms and conditions. They also shape their particular projects to meet the selection criteria at hand from different funders. To date, however, our analysis of research funding has focused almost exclusively on the supply-side, with little or no insight into demand-side issues.
4. Do mechanisms such as matching grants, university-industry alliance funding, or other joint mechanisms reduce crowding out while promoting

high level of scientific openness? Matching grants are designed to allow self-selection away from projects that might be inefficiently funded. However, they increase the need for commercial returns in order to be viable. Such motivations may conflict with goals of scientific openness.

5. Do open licensing requirements stimulate scientific openness? The chapter identifies a complementarity between the strength and effectiveness of intellectual property protection and commercial interests to permit scientific disclosure. Open licensing requirements may promote greater use of scientific outputs, but at the same time they weaken intellectual property protection's role in facilitating scientific openness. In an area where open licensing emerged as a new requirement, this would provide an empirical environment to test such claims.

6. Do foundations play a complementary role in the research-funding complex? How does their stated social mission interact with their emphasis on funding projects of high scientific merit? This chapter provides a framework within which to analyze the implications of foundations' growing commitment to rapid and full disclosure, alternative commercialization rights, and public-private collaborations.

These questions are central to analyzing the effectiveness of current mechanisms and processes attached to public funding of research and development. As noted in the introduction, significant, ongoing, and unresolved issues remain in the arena of the public support of science with regard to the efficiency whereby capital funds are directed. We believe that this agenda is necessary to understand some of the new trade-offs explored in this chapter.

References

Aghion, P., M. Dewatripont, and J. Stein. 2009. "Academic Freedom, Private-sector Focus and the Process of Innovation." *RAND Journal of Economics* 39 (3): 617–35.

ARPA-E. 2010a. ARPA-E Broad Funding Announcement. http://arpa-e.energy.gov/.

ARPA-E. 2010b. ARPA-E Mission. http://arpa-e.energy.gov/About/Mission.aspx.

ARPA-E. 2010c. ARPA-E Programs Main Overview. http://arpa-e.energy.gov/ProgramsProjects/Programs.aspx.

Arrow, K. 1962. "Economic Welfare and the Allocation of Resources for Invention." In *The Rate and Direction of Inventive Activity: Economic and Social Factors,* Universities-National Bureau Committee for Economic Research and the Committee on Economic Growth of the Social Science Research Councils, 609–25. Princeton, NJ: Princeton University Press.

Azoulay, P., J. Graff Zivin, and G. Manso. 2010. "Incentives and Creativity: Evidence from the Howard Hughes Medical Investigator Program." Working Paper.

Banal-Estañol, A., and I. Macho-Stadler. 2010. "Scientific and Commercial Incentives in R&D: Research versus Development?" *Journal of Economics and Management Strategy* 19 (1): 185–221.

BBSRC (Biotechnology and Biological Sciences Research Council). 2011. Cross Council Research Grant Terms and Conditions. www.bbsrc.ac.uk/web/FILES/.../research-grants-terms-conditions.pdf.

Biagioli, M. 2000. "Replication or Monopoly? The Economies of Invention and Discovery in Galileo's Observations of 1610." *Science in Context* 13 (3–4): 547–90.

Blumenthal, D., E. Campbell, N. Causino, and K. Seashore Louis. 1996. "Participation of Life-Science Faculty in Research Relationships with Industry." *New England Journal of Medicine* 335:1734–9.

Blumenthal, D., E. G. Campbell, M. Gokhale, R. Yucel, B. Clarridge, S. Hilgartner, and N. A. Holtzman. 2006. "Data Withholding in Genetics and the Other Life Sciences: Prevalence and Predictors." *Academic Medicine* 81 (2): 137–45.

Bush, V. 1945. "Science: The Endless Frontier." A Report to the President. Washington, DC: US Government Printing Office.

Clemins, P. J. 2010. "Historical Trends in Federal R&D." Chap. 2 in *American Association for the Advancement of Science Report XXXIV: Research and Development FY2010.* Washington, DC: American Association for the Advancement of Science.

Dasgupta, P., and P. A. David. 1994. "Towards a New Economics of Science." *Research Policy* 23:487–521.

David, P. A. 2008. "The Historical Origins of 'Open Science': An Essay on Patronage, Reputation and Common Agency Contracting in the Scientific Revolution." *Capitalism and Society* 3 (2): Article 5.

Furman, J., F. Murray, and S. Stern. 2010. "More for the Research Dollar." *Nature* 468:475–8.

Gans, J. S., F. Murray, and S. Stern. 2010. "Contracting Over the Disclosure of Scientific Knowledge: Intellectual Property and Academic Publication." MIT Working Paper.

Groopman, J. 2001. "The Thirty Years' War." *Annals of Medicine, The New Yorker* June 4: 52.

Haack, S. 2006. "Scientific Secrecy and Spin: The Sad, Sleazy Saga of the Trials of Remune." *Law and Contemporary Problems,* Vol. 69. University of Miami Legal Studies Research Paper no. 2007-02. Available at: http://ssrn.com/abstract=938485.

Henderson, R., A. B. Jaffe, and M. Trajtenberg. 1998. "Universities as a Source of Commercial Technology: A Detailed Analysis of University Patenting, 1965–1988." *Review of Economics and Statistics* 80 (1): 119–27.

Huang, K., and F. Murray. 2009. "Does Patent Strategy Shape The Long-Run Supply Of Public Knowledge? Evidence from the Human Genome." *Academy of Management Journal* 52 (6): 1193–221.

Judson, H. F. 1979. *The Eighth Day of Creation: The Makers of the Revolution in Biology.* New York: Cold Spring Harbor Press.

Kenney, M., and D. Patton. 2009. "Reconsidering the Bayh-Dole Act and the Current University Invention Ownership Model." *Research Policy* 38:1407–22.

Kitch, E. W. 1977. "The Nature and Function of the Patent System." *Journal of Law & Economics* 265:274–5.

Litan, Robert E., Lesa Mitchell, and E. J. Reedy. 2007. "Commercializing University Innovations: Alternative Approaches." Available at: http://ssrn.com/abstract=976005.

Machlup, F., and E. Penrose. 1950. "The Patent Controversy in the Nineteenth Century." *Journal of Economic History* 10 (1): 1–29.

Maurer, S., and Suzanne Scotchmer. 2004. "Profit Neutrality in Licensing: The Boundary between Antitrust Law and Patent Law." NBER Working Paper no. 10546. Cambridge, MA: National Bureau of Economic Research, June.

Merton, R. K. 1957. "Priorities in Scientific Discovery: A Chapter in the Sociology of Science." *American Sociological Review* 22 (6): 635–59.

Mokyr, J. 2004. *The Gifts of Athena.* Princeton, NJ: Princeton University Press.

Mowery, D., R. R. Nelson, B. Sampat, and A. Ziedonis. 2004. *Ivory Tower and Industrial Innovation—University-Industry Technology Transfer.* Palo Alto, CA: Stanford University Press.

Mowery, D.C., and B. N. Sampat. 2001. "Patenting and Licensing University Inventions: Lessons from the History of the Research Corporation." *Industrial and Corporate Change* 10 (2): 317–55.

Mowery, D.C., and A. A. Ziedonis. 2002. "Academic Patent Quality and Quantity Before and After the Bayh-Dole Act in the United States." *Research Policy* 31: 399–418.

Mukherjee, A., and S. Stern. 2009. "Disclosure or Secrecy: The Dynamics of Open Science." *International Journal of Industrial Organization* 27:449–62.

Murray, F. 2002. "Innovation as Co-evolution of Scientific and Technological Networks: Exploring Tissue Engineering." *Research Policy* 31 (8–9): 1389–1403.

Murray, F., and S. Stern. 2007. "Do Formal Intellectual Property Rights Hinder the Free Flow of Scientific Knowledge? An Empirical Test of the Anti-commons Hypothesis." *Journal of Economic Behavior and Organization* 63 (4): 648–87.

Nathan, D. G., and D. J. Weatherall. 2002. "Academic Freedom in Clinical Research." *New England Journal of Medicine* 347:1368–71.

National Academy of Sciences. 2007. *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future.* Washington, DC: National Academies Press.

Nelson, R. R. 1959. "The Simple Economics of Basic Scientific Research." *Journal of Political Economy* 67 (3): 297–306.

OECD. 2002. *Frascati Manual: Proposed Standard Practice for Surveys on Research and Experimental Development.* Paris: OECD.

Office of Sponsored Programs, MIT. 2011. MIT Template Research Agreement. http://osp.mit.edu/sites/osp/files/u9/mit_research_agreement_for_us_sponsors_050111_website_version.pdf.

Olivieri, N. F., G. M. Brittenham, D. Matsui, M. Berkovitch, L. M. Blendis, R. G. Cameron, R. A. McClelland, P. P. Liu, D. M. Templeton, and G. Koren. 1995. "Iron-Chelation Therapy with Oral Deferiprone in Patients with Thalassemia Major. *New England Journal of Medicine* 332:918–22.

Owen-Smith, J. 2005. "Dockets, Deals, and Sagas: Commensuration and the Rationalization of Experience in University Licensing." *Social Studies of Science* 35 (1): 69–97.

Romer, P. M. 1990. "Endogenous Technological Change." *Journal of Political Economy* 98 (5): S71–102.

Schiebinger, L., and C. Swan, eds. 2005. *Colonial Botany: Science, Commerce, and Politics in the Early Modern World.* Philadelphia: University of Pennsylvania Press.

Scotchmer, S., and J. Green. 1990. "Novelty and Disclosure in Patent Law." *Rand Journal of Economics* 21 (1): 131–40.

Sloan Foundation. 2008. Apply for Grants. http://www.sloan.org/apply/page/4.

Sponsored Projects Office, University of California, Berkeley. 2011. http://www.spo.berkeley.edu/Forms/UCForms.html.

Stern, S. 2004. "Do Scientists Pay to be Scientists?" *Management Science* 50 (6): 835–53.

Stokes, D. 1997. *Pasteur's Quadrant: Basic Science and Technological Innovation.* Washington, DC: The Brookings Institution.

Stroup, A. 1990. *A Company of Scientists: Botany, Patronage, and Community at the Seventeenth-Century Parisian Royal Academy of Sciences.* Berkeley: University of California Press.

Williams, H. 2010. "Intellectual Property Rights and Innovation: Evidence from the Human Genome." Harvard Working Paper.

Comment

Suzanne Scotchmer

The Role of Disclosure in R&D

Political and economic debates about innovation policy tend to center on intellectual property, and its defects as an incentive mechanism. This is because intellectual property involves a complex set of rules and objectives that interact and are hard to evaluate, and also because intellectual property is a well-defined body of law in law school curriculums. However, the complexity of intellectual property law pales beside the complexity of the public funding system. A nice contribution of the Gans and Murray chapter is that it illuminates the complexity of the public funding system.

The focus of the chapter is on disclosure requirements. The chapter begins with a survey of the rules that are imposed by various funding agencies. These requirements have apparently accreted over time without a well-articulated objective. The rules consequently seem fragmented. My takeaway from this hodge-podge is that the purposes of disclosure are not well understood.

There is a very immediate purpose for disclosure in patent law, namely, notice. Without disclosure, what is protected? Notice is clearly important, but does not leave much room for economists to think strategically about why patent applicants want to minimize what is disclosed, or why disclosure is good for society as a whole. There are clearly other issues involved, else patent applicants would not seek to minimize their disclosures.

For example, an industrial context where not much disclosure is required is computer software. Patent practice has evolved such that very little useful knowledge needs to be disclosed by the applicant (see Lemley et al. 2002, 204–205). For copyrighted works, disclosure ought to be automatic because copyright protects "expression." However, it is not quite clear what is expressive in computer software, especially since software can be distributed in compiled form. Oddly enough, for copyrighted source code, US Copyright Circular 61 contains an explicit exemption from full disclosure, rather than a requirement for full disclosure. This raises more questions than it answers.

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