Funding Conditions, the Public-Private Portfolio and the Disclosure of Scientific Knowledge*

by

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Preliminary

This paper investigates project selection choice and conditions imposed by public funders (both governmental and non-governmental) and the impact of these on the portfolio of public and private research projects funded, their commercialization and the level of openness in funded research. We begin by reviewing project selection criteria and policies towards disclosure and commercialization (including patent rights); noting significant variability across funders in these. We then provide a model of how funding conditions that restrict commercialization opportunities impact on the projects that accept public funds and the overall level of openness in research. Implications for empirical evaluation and an agenda for future research are outlined. *Journal of Economic Literature* Classification Number: O34.

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1. Introduction

Understanding the magnitude of public support for research – in particular, for basic research – and its interaction with private research support is a central issue in the economics of invention and innovation. As Arrow (1962) famously described, the strong theoretical arguments that private incentives to fund research are well below social incentives is reason to presume that, absent public funding, not only is the rate of inventive activity suboptimal but that its direction will be biased towards more applied, 'close to market' outcomes.

Fifty years on, the theoretical rationale for public intervention in support of invention remains unchallenged and in the years following World War II public intervention in research has been recognized and institutionalized (Bush, 1949). Nonetheless, public R&D providers find themselves in the cross-hairs of an ongoing debate; little consensus exists as to how such support should be provided. On the one hand, public funders are repeatedly asked to account for the impact of their funding choices and criticized when the basic research that they fund has not led in the direction of real-world impact. Take, for example, the critique of the cancer research spending by the National Cancer Institute (NCI). Forty years after Nixon announced the War on Cancer, many have accused the NCI of overemphasizing basic research to the detriment of more translational projects that maximize patient impact (Groopman 200x). On the other hand, when agencies shift their funding toward near-term mission-oriented R&D projects, they are criticized for either crowding out what industry would have done otherwise or funding parallel (seemingly redundant) efforts.

This view is 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 indeed would "race" the public effort to completion. Observers argued that the public funding was 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). This rationale for public funding emphasizes more recent perspectives on public research support. According to this argument, public researchers can ensure the broad disclosure of research findings and, thus, enable the inter-temporal spillovers that are critical to long-term growth. This is achieved both through the contractual provisions of their funding but more broadly because of the norms and incentives for openness and disclosure grounded in the institutions of Open Science in which public researchers (university academics) generally operate (Dasgupta & David 1994; David 2004).

To reconcile these two seemingly distinct perspectives on public research funding – the **selection view** that it is grounded in supporting basic projects that might not otherwise be funded and the **disclosure view** that it is predicated on the openness and knowledge accumulation it supports, we develop a theoretical model that considers demand and supply of public research funds. The supply of those funds is determined both by the selection criteria of funding organizations and also on those organizations' choice of conditions on funding. The demand for those funds comes from scientists that choose to accept funding offers or not based on their outside options. In particular, some projects may be able to attract private funding. Specifically, our contention here is that public funders (both governmental and non-governmental) do not impact on invention solely by adding resources to those activities. Their

impact arises in both the way they select projects to support and the conditions they attach to the dissemination and commercialization of those projects. And both likely have an impact on the direction of inventive activity.

It is not our intention here to review the literature on the issues associated with the public support of inventive activity. Instead, to understand the intellectual foundations of our approach, it is useful to re-consider two classic arguments put forward by Nelson (1959) on the funding of basic research that highlight the role of different funders in selecting different types of research and the different disclosure requirements that follow.

Nelson's central point about the role of different funders has, in our opinion, been under-appreciated. He argues 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. (p.304, Emphasis in original)*

In other words, concerns that public grants to inventive activity are wasteful over-expenditures that crowd out private activity are misplaced precisely because that private activity continues. The period from 1953 to 2008 has underscored this point of view with US total R&D expenditures have risen from $25Billion to US$350Billion in constant dollars ($400Billion in real terms in 2008) – more than a six-fold increase (S&E Indicators Figure 4-1). Not simply a rise in Federal (public) funding, which has risen from around $12Billion to around $80Billion annually, the amount of R&D funding from industry experiencing the highest growth from a similar starting point to over $200Billion. Thus, while the 1950s saw a period where industry and Federal contributions were approximately equal, industry funding of R&D is now almost three times that of the Federal government. Put simply, taking Nelson's argument seriously implies that the growth in private funding is itself a statement on the degree to which efforts in

public support should be increased. The possibility that some public funding is, in fact, purely wasteful, only strengthens the case that opportunities exist to enhance support to promote more socially valuable inventive activity.

In prescribing the role of public support, Nelson (and many others) found it useful to classify research projects along a continuum from basic to very applied. Under this schema, the key concern was that private funders pursued too little basic research relative to the amount applied research that is undertaken. The funding landscape turns out to be more complex: First, industry itself provides funding to universities to undertake research. Second, industry itself does some basic research. Third, public funding is spent in academia on mission-oriented near-term objectives.

Our mapping of the selection criteria for public funding requires more nuance. As emphasized by Stokes (1997), 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; the leading example being Pasteur's simultaneous discover of the small pox vaccine and advances in microbiology. The fact that significant numbers of projects lie in Pasteur's Quadrant is confirmed by the existence of patent-paper pairs where research is simultaneously patented and published suggesting both immediate commercial value and scientific merit (Murray, 2002; Murray and Stern, 2007). This suggest that, at the very least, when examining the effect of public support for inventive activity on its direction we should consider a two dimension space for projects characterized by the degree of scientific merit on one dimension and the extent of immediate valuable application on the other. Scientists preferences for these different quadrants is poorly understood but the fact that university scientists often engage in patenting and publishing as outputs of the same project

implies that many enjoy both traditional "basic" research of scientific merit but also engaging in projects that lie in Pasteur's Quadrant (Murray 2002; Azoulay, Ding & Stuart 2007).

Nelson went further, however, and argued that there were institutional comparative advantages associated with research that might be performed with public funding. His starting point was that:

> *... there is a basic contradiction between the conditions necessary for efficient basic research – few or no constraints on the direction of research with full and free dissemination of research results – and full appropriation of the gains from sponsoring basic research in a competitive economy. (p.305)*

The institutional foundations that establish the setting, incentives and mechanisms to ensure such freedom and openness have been elaborated by David and others. In addition, Mokyr (2002) emphasizes their importance in ensuring long-run knowledge accumulation and inter-temporal spillovers. Together these lines of scholarship build on and broaden Nelson's notion that basic research requires conditions of openness to arguing that any type of research that is disclosed is itself far more socially valuable than research held secret. And illustrating that it is academia and Universities that provide an institutional means of promoting research that is in the public domain regardless of its place along a single continuum or in Pasteur's Quadrant. The preference of scientists to operate with freedom to disclose is borne out in subsequent empirical research demonstrating that scientists seeking employment in industry were offered higher pay in return to agreeing to less open research environments (in terms of publication and other academic activities) (Stern 2004). This serves to emphasize both scientist preferences for such activities and the fact that those activities are (at times) in conflict with commercial outcomes. Thus, it is not simply a matter of looking at the level of public support for selective types of inventive activity but also if it is occurring in settings and under conditions promoting open research dissemination rather than secrecy – buried within products and applications.

Taking disclosure as the central issue in understanding research funding, research has emphasized variability in the amount of profit that can be appropriated from inventive activity (see, for example, Romer 1990 and Scotchmer and Maurer, 2004). In this situation, the concern is that private funding may be concentrated amongst highly appropriable projects but, interestingly, that blanket public support may not select the most socially valuable projects and more sophisticated mechanisms should be employed to screen projects and also to ensure quality.[1] If we combine this with the idea that commercial profits are harmed by openness, then by insisting on full disclosure of research results, public funders can perhaps ensure that projects that might otherwise be capable of private appropriation do not end up claiming those funds. Consequently, as will be demonstrated below, disclosure requirements attached to public support may, in fact, lead to research outcomes with some scientific merit being kept in secret or sparingly disclosed.

Our contention here is that the conditions attached to public support of inventive activity will impact both on the mix of projects funded but also on the openness of those projects through a market that emphasizes the preferences of both the funders themselves but also the scientists and the types of projects and disclosures they prefer. The design of research contracts by public or publicly spirited funders is an issue that has been understudied. To be sure, elements of this problem arise in debates about the interaction between commercial interests and academic norms. Moreover, the introduction of the *Bayh-Dole Act* was itself a change in the nature of particular research contracts. But the larger problem of what conditions are actually attached to research contracts and how they impact the inventive activity undertaken is an open question. Studying it would be a critical input into informing on research contract design as well

[1] Weyl and Tirole (2010) take a mechanism design approach to look at how intellectual property protection alters the selection of privately funded projects.

as the mission and orientation of public funding agencies.

Some 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.[2] With regard to openness, Mukherjee and Stern (2009) and Gans, Murray and Stern (2010) examine the impact of commercialization options on the disclosure rights afforded research scientists. None of these investigations, however, examine how public funding conditions impact on the mix of private-public projects and with it the level of disclosures across the whole system.

The purpose of this paper is provide a model that allows us to consider the mix of public-private projects in the 2x2 space that includes the two dimensions of scientific merit and immediate applicability and to consider the different disclosures that can and do arise in each quadrant. The model motivates a broader agenda for the study of the contract design problem facing public research funders. Our focus is on research that is performed in Universities but many of the things we address have broader applicability. To this end, the paper does three things:

First, in Sections 2 and 3, we provide an overview of preferences of funding organizations across different types of research project and disclosure regimes. Section 2

[2] Along similar lines, there is a theoretical literature examining the role of technology transfer offices within Universities (see XXXX).

reviews the selection criteria in government and non-government funding organizations – specifically focusing on their choice of projects along the two dimensions of scientific merit and immediate applicability. Then in Section 3, we examine conditions on disclosure and commercialization of research project outcomes.

Second, in Section 4, we provide a model of the demand and supply of public research funds. The supply of those funds is determined by the selection criteria of funding organizations and also by those organizations' choice of conditions on funding. The demand for those funds comes from projects that choose to accept funding offers or not based on their outside options. In particular, some projects may be able to attract private funding. We demonstrate that funding conditions determine, in part, the 'price' of public funds and so will impact on the mix of projects accepting those funds. Our chief finding is that, in the absence of public funding, many projects with high scientific merit and immediate applications will be funded and, in fact, also disclosed in an open manner. Public support, offered with conditions attached that restrict commercialization (e.g., patents), will not be attractive to such projects and so a natural screen occurs. However, unrestricted public funds will cause those projects to accept funding leading to fewer projects funded overall without consequent gains in openness. This has implications as to how we would empirically evaluate the *Bayh-Dole Act* as well as the way funding organizations should think about the conditions they impose.

Finally, in Section 5, based on our analysis, we outline an agenda for future research. This agenda is motivated by the fact that we have limited knowledge at the moment of the actual outcomes – selection and openness – of publicly funded projects as well as the baseline trade-offs that our theoretical model has identified.

2. Selection Criteria in Funding Organizations

The criteria used by funding organizations in the selection of their research portfolio have been the subject of surprisingly little empirical analysis. The most traditional approach to considering this problem (and one that continues to dominate many funding agencies) is the linear view of innovation (Bush 1949, Nelson 1959). However, as emphasized by Stokes (1997), research projects are not necessarily basic (advancing scientific knowledge) or applied (leading to immediate applications). In some instances, projects explicitly involve both; Galileo not only developed significant scientific insights that contributed to astronomy while observing the moons of Jupiter, Venus and other plants but also made useful advances in optics with implications for the nautical community (Biagioli 2004). Genomics provides a more recent example of research that is at once useful and scientifically interesting. Likewise, research on chip design in the 1960s and 1970s, funded by DARPA was also considered to be critically useful but also scientifically important. Some projects, such as the development of theories of plate tectonics or the big bang theory, are in fact explicitly being generated to advance scientific knowledge. Likewise, other research projects funded by DARPA can be focused specifically on meeting a particular short-run practical objective (such as their program to develop gallium arsenide RF technology that enabled the cellular commercial infrastructure). Nonetheless, the fact that significant numbers of projects lie in Pasteur's Quadrant suggests that, when examining the effect of public support for inventive activity on its direction we should consider a two dimension space for projects characterized by the degree of scientific merit on one dimension and the extent of immediate valuable application on the other.

In this section, we map the stated ways in which different types of funders – both public and private as well as not-for-profit private foundations - select the projects they fund. We base

our analysis on current documentary evidence available from these funders. Although, by necessity, this is less detailed than an examination of the actual funding choices eventually pursued (or those that are available through the application by researchers for funding), it does lend insights into the hitherto undocumented selection process that is an essential input into the market in which funders and researchers negotiate over projects and determine the final portfolio of R&D projects.

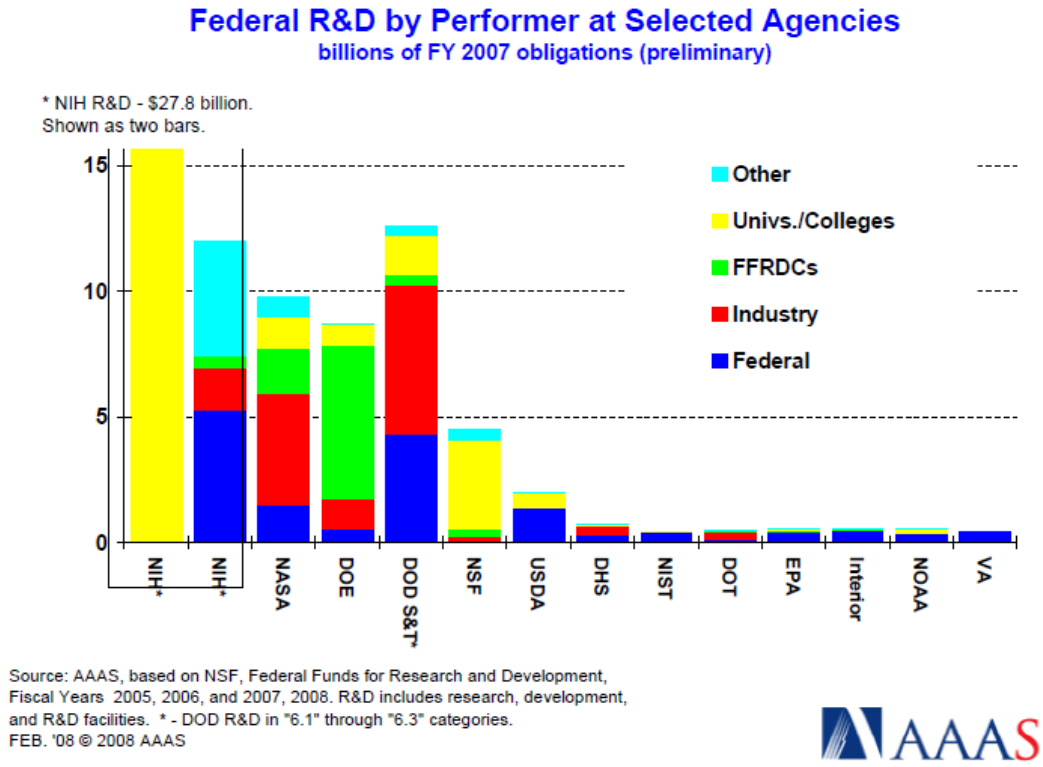
In what follows, we provide the broad context for public R&D funding and data to elaborate trends in the fifty-year period the Rate and Direction volume was published. We then examine the broad funding mission for public, not-for-profit and private funders as well as information regarding the specific selection criteria used to evaluation grants of different kinds. One note however; because private funders generally do not use public "calls for proposals", information on selection criteria are limited.

Levels of Federal Funding

U.S. Federal government funding committed for research has risen steadily in the past several decades to around $80Billion annually. Of this total, more than 60% is undertaken by academic researchers within universities whose focus is broadly on enabling the progress of science (with much of the remainder by government laboratories). The graph below, taken from AAAS sources, illustrates both the funding agencies and the researcher performer. It illustrates that, at least in recent years, the National Institutes of Health (NIH) dominates Federal funding for R&D (when only science and technology Department of Defense funding is included)[3]. However, the Department of Defense (DOD) is the third-largest federal sponsor of academic

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

research behind only the National Institutes of Health (NIH) and the National Science Foundation (NSF) (AAAS, 2010). Funds are disbursed through at least four major funding agencies each of which receives annual appropriations from Congress. In recent years, the Department of Energy has also engaged in more significant R&D spending with funding going to academia. In what follows we examine these four major government funding sources to academic researchers in more detail.



With the founding of the National Science Foundation in the 1950s -- following Vannevar Bush's 1945 "Endless Frontier" report to President Truman and a series of legislative attempts to establish government support for basic research – the principle of public funding to support innovation, economic growth and the pursue of knowledge within academia was established in its modern form. Its first grants were awarded in 1952 and would little change

over the intervening period, the agency's mission has remained to "to promote the progress of science; to advance the national health, prosperity, and welfare; to secure the national defense…" (see http://www.nsf.gov/about/glance.jsp) . More explicitly, the funding criteria are focused 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." (see http://www.nsf.gov/about/glance.jsp) . Of all the funding agencies, the National Science Foundation is perhaps the most committed to and explicit in its support for scientific knowledge production based on criteria of long term scientific merit. 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 through a capable and responsive organization. We like to say that the NSF is "where discoveries begin." Funding has included a national series of Observatories (in 1955) and the South Pole Station (in 1957) and, in the 1980s, major funding for the Internet backbone. At its current funding levels the Foundation accounts for about 20% of research funding in academic institutions.

While the specific selection criteria vary by grant, the NSF has initiated a new mechanism focused on early-stage research that is intended to be of a more risky nature. The EAGER mechanism is intended to "support exploratory work in its early stages on untested, but potentially transformative, research ideas or approaches" (http://www.nsf.gov/pubs/policydocs/pappguide/nsf10_1/gpg_2.jsp#IID2). Specifically, it funds

research with expectations of "high risk-high payoff" in the sense that it, for example, involves radically different approaches, applies new expertise, or engages novel disciplinary or interdisciplinary perspectives."

The more standard NSF grant approach is to ensure that investigators address both the intellectual merit of the proposed activity; and the broader impacts resulting from the proposed activity in their proposals. These are defined along fairly standard lines by the NSF, specifically:

> **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? (http://www.nsf.gov/pubs/policydocs/pappguide/nsf10_1/gpg_3.jsp)
>
> **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 mission oriented funding into academic research from the National Institutes of Health, Department of Energy and the Department of Defense stand in contrast to the NSF approach mixing basic intellectual merit criteria for selection with more explicit mission-focused criteria focusing research projects towards more immediate impact criteria. As of 2010, the NIH budget is over US$25Billion (excluding ARRA funding) with more than 80% going to fund research at over 3,000 universities and research institutions[4]. The blended mission is evident in the articulation of the NIH funded research that has "paved the way for important

[4] 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 & G12.

discoveries that improve health and save lives" (http://www.nih.gov/about/). The mission orientation of NIH funded is grounded in the history of the institute: In 1798 the Marine Hospital Service was established by President John Adams for the treatment of seamen and later extended to officers of the U.S. Navy. Its role in research was initiated almost 100 years later when Congress appropriated funds to study the causes of epidemic diseases, "especially yellow fever and cholera" (NIH Almanac). This initiative 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 investments were a bacteriology laboratory on Staten Island focused on research – a facility that later moved to Washington D.C. and became the foundation of the Hygienic Laboratory (a precursor to the intramural research facility in Bethesda). It was not until 1912 that the research program of the service (now known as the Public Health Service) expanded beyond communicable diseases and in 1918 the practice of making grants to outside institutions (25 in total) was initiated 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. At least by 1983 intramural funding had become less than 20% of the overall budget spend on research grants ($560M in 1983 compared to $2.4B on research grants) – a trend that continued today with a $3B intramural budget compared to a $21B extramural research grant budget.

The orientation, particularly of the NIH today, is well captured in the mission of the NIH which is "to improve human health by increasing scientific knowledge related to disease and health" (NIH Grants Policy Statement General Information 12/03) through the support of biomedical and behavioral research. While the overall mission is clearly defined, individual institutes (ICs) have their own mission and are governed through separate appropriations.

Broadly speaking, the NIH allocates awards (for research rather than infrastructure) through Pas or RFAs. A TA describes new, continuing or expanded program interests. In contrast, an RFA is a more targeted solicitation focused on well-defined scientific areas or for a one-time competition. In selecting external awardees, the NIH uses a peer review system, a required legally 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) p. 7). Much like the NSF the NIH review criteria are clearly laid our with the goal to "advance the understanding of biological systems, improve the control of disease, and enhance health." In this context, review is supposed to determine whether the research will "impact on the pursuit of NIH's research goals." Five criteria are defined in the Congressional guidelines:

- *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?(* (http://grants.nih.gov/grants/policy/nihgps_2003/NIHGPS_Part3.htm#_Toc54600045)

Interestingly there is no discussion of immediate application. Nor is there a discussion of appropriability. While this is seemingly at odds with the broader goal of advancing human

health, the specific funding choices at the level of particular grant mechanisms highlights these choices. More specific guidance is provided for projects in the R21 category (Exploratory Research Grant Program) designed to support "novel scientific ideas or new model systems, or technologies that have the potential fro significant impact on biomedical…research." Reviewers in the "Definitions of Criteria" are directed to focus their evaluation on the "conceptual framework, the level of innovation and the potential to significantly advance our knowledge or understanding".

Unlike the NSF and NIH, the Department of Energy (DOE) has not historically been an organization primarily devoted to research funding. 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). However, the focus of the Department has shifted over time. The DOE originally emphasized "energy development and regulation" in the late 1970s, "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). Currently, 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 funds 40% of the basic research in the physical sciences in the United States, making the single largest supporter of such research. Nonetheless, the DOE's strategic theme of science, discovery and innovation accounted for only 16%, or $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 the *American Recovery and Reinvestment Act* (ARRA), the DOE is not primarily focused on research funding despite its current mission.

Even though the majority of DOE supported research is performed internally in 17 national laboratories, the Department does solicit grant applications through its Office of Science (DOE Office of Science: Grants & Contracts 2010). The Office of Science is subdivided into six program offices, Advanced Scientific Computing Research, Basic Energy Sciences, Biological and Environmental Research, Fusion Energy Sciences, High Energy Physics and Nuclear Physics, each with their own mission (DOE Office of Science: About the Office of Science 2010). However, unlike the ICs in the NIH, these program offices are neither governed by separate appropriations nor do they have independent grant evaluation and selection criteria. The DOE Office of Science allocates research grants through funding opportunity announcements (FOAs) that are generally focused on well-defined research goals for a one-time competition, similar to NIH RFAs. However, the DOE also publishes annual FOA's, which broadly solicit supplemental and renewal applications for continued DOE program objectives. The DOE uses a peer review system to select its awardees, as legally required through the Office of Science Financial Program Rule (10 CFR Part 605 2006), in order "to determine the very best scientific proposals to support" (DOE Office of Science: About the Office of Science 2010). These criteria, in descending order of importance, are:

- **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**; **and**
- **Other appropriate factors, established and set forth in a notice of availability or in a specific solicitation.** (Basic Energy Sciences: Review and Selection of Research Projects 2010; 10 CFR 605.10)

DOE funded research has included the initiation of the Human Genome Project (in 1986) and continued the tradition of pioneering research into nuclear medicine exhibited by its predecessor organizations since the 1940s (DOE Office of Science: Basic Research with Historic Results 2010). In response the National Academies 2006 report, "Rising Above the Gathering Storm," the America COMPETES Act of 2007 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: Programs Main Overview 2010).

ARPA-E is modeled after the Defense Advanced Research Projects Agency (DARPA) and received $400 million in initial funding through ARRA in 2009. Its mission is to "fund projects that will develop transformational technologies that reduce America's dependence on foreign 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: Mission 2010). 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: Mission 2010). ARPA-E has released seven FOAs to date, six of which have a narrow research focus similar to traditional DOE FOAs (ARPA-E: Programs Main Overview 2010). 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: Broad Funding Announcement). ARPA-E uses a peer review process to select awardees with the following evaluation criteria:

- **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 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. (DE-FOA-0000289; DE-FOA-0000290)

While these criteria are remarkably similar to those used by the DOE Office of Science, they do place additional emphasis on novelty and impact.

The United States Department of Defense (DOD) spent $82 billion on research, development, testing, and evaluation (RDT&E) in fiscal year 2008 (National Science Foundation 2008). This is nearly 50% more than the $56 billion spent on RDT&E by rest of the federal government combined (National Science Foundation 2008). However, very little of this funding reaches academic institutions. 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; but focuses its spending on the later five (DOD Financial Management Regulation 2008). In fact, this focus is so extreme that in fiscal year 2009 only 2.1% of the DOD's RDT&E budget was dedicated to basic research and 5.3% was dedicated to applied research (DOD Budget: Fiscal Year 2009 2008). This is further reflected in the organizational structure of the DOD, as university research is one of the mandates supported by one of four organizations within the Research Directorate; which is itself one of four directorates under the Office of Defense Research & Engineering. In fact, nearly all of the basic research and much of the applied research supported by the DOD is funded through DARPA, which is 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, DARPA's 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" (DARPA Mission 2010). For DARPA, this "research" takes the form of basic research, applied research, and advanced technology development as defined by the DOD. It operates through seven independent offices: the Adaptive Execution Office, the Defense Sciences Office, the Information Processing Techniques Office, the Microsystems Technology Office, the Strategic Technology Office, the Tactical Technology Office, and the Transformational Convergence Technology Office (DARPA Offices 2010). These offices are similar to the NIH's ICs in that they have independent missions and identify their own research agendas, however, like the program offices in the DOE Office of Science, their funds are not appropriated independently. Each

office posts solicitations for research proposals in the form of Broad Agency Announcements (BAAs), which are similar to NIH RFAs and DOE FOA's in their specificity of research requested (DARPA Solicitations 2010). While the independence given to each office leads to variability within the evaluation criteria used across BAA's, these criteria are present in each BAA:

- **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 particular mission and methods assessed. Specifically, DARPA's mission seeks to maintain the technological superiority of the U.S. military and prevent technological surprise from harming U.S. national security. 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. (DARPA-BAA-10-35 2010, DARPA-RA-10-76 2010)

It is clear that ARPA-E's mission focused evaluation criteria were modeled on the above, however it has yet to be seen whether ARPA-E can promote innovations in a way that matches DARPA's role in the creation of the Internet.

Foundations

The recent rise of foundations, particularly in the arena of biomedical research provides

an alternative perspective on the types of selection criteria that can be used to judge and select research projects within academic institutions. Most foundations – for instance, the Sloan Foundation – follow selection criteria that are not too different from the Public Funding Agencies; emphasizing scientific rather than applied outputs.

The Bill & Melinda Gates Foundation, is a particularly interesting example of a foundation with significant resources but a much greater emphasis on solving problems of immediate social and economic value. The overall foundation statement highlights this by outlining its commitment to selecting projects by asking the following questions (http://www.gatesfoundation.org/grantseeker/Pages/foundation-grant-making-priorities.aspx):

- 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% of the US$22Billion in funding that the foundation has committed from 1994 through June 2010) the priority areas are defined by disease and include diarrhea, malaria, polio and tuberculosis – a list strikingly similar to the priorities and emphasis of the NIH in the late half of the nineteenth century and early twentieth century. More specifically, within their Explorations program, the foundation highlights the funding (at levels of $100k per project), "unorthodox thinking…essential to overcoming the most persistent challenges in global health…to expand the pipeline of ideas to fight our greatest health challenges" (www.grandchallenges.org/explorations/). The funding criteria are dramatically different from the approach used in Federal funding. Projects are funded that represent an explicitly innovative approach to the topic (rather than currently accepted paradigms). Topics are outlined for each Grand Challenge Exploration

Proposals are not explicitly subject to "peer review." Instead, the review panel has

"broad expertise and a track record in identifying innovations." They may not be deep domain expertise 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 incremental advances. In the second step, external reviewers make evaluations but rather than seek consensus, can making funding recommendations based on the best proposals they see. Three criteria are deemed critical (Rules and Guidelines: Grand challenges Explorations Round 4):

- **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?

As an example of a priority topic area, the most recent Grand challenge Explorations is focused on new technology for contraception. The Foundation starts its definition of the topic and thus the selection criteria with the articulation of a key "roadblock". Specifically they argue that

> *... 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. It is estimated that 200 million women in developing countries have an unmet need for effective contraception even while family planning is one of the most cost effective ways to reduce maternal, infant and child mortality.*

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 especially 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 … etc." They conclude with their statement of need – to

> *... solicit novel and innovative approaches to preventing unintended pregnancy. We seek 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. (http://www.grandchallenges.org/Explorations/Topics/ContraceptiveTechnologies/Pages/round4.aspx)*

3. Disclosure and Commercialization

For society as a whole, disclosure is a key element shaping the impact of investments in research by both the public and the private sector on the economy. As is increasingly recognized, the mere production of knowledge is inadequate to ensure its role in knowledge accumulation: inter-temporal knowledge spillovers require that knowledge be disclosed and accessible to others, a feature of knowledge production that is far from axiomatic (Mokyr 2004). While of broad social importance, disclosure outcomes are typically negotiated between researchers and funders as they match on particular research projects, with a key issue being the preferences of each party for control over disclosure of the scientific knowledge produced as a result of the project. In particular, while scientists are of course interested in control over the selection of research direction (as outlined by Aghion, Dewatripont and Stein 2008), they are also concerned with the degree of control rights vested in them by the particular funder (whether public or private in nature) regarding disclosure.

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 particular disclosure strategies. In particular, while researchers have strong preferences for disclosure in the form of academic

publications, funders may have expectations that research is disclosure through intellectual property (IP) rights or may prefer secrecy. Of course, as documented elsewhere, these two forms of disclosure are not mutually exclusive: for research projects that produce outcomes of both immediate usefulness and make a contribution to long-run knowledge accumulation, both patents and papers may be potential sources of disclosure. When these two outcomes arise out of a single project then we see disclosure in the form of patent-paper pairs (Murray 2002; Murray and Stern 2007). As a consequence, four institutional paths for knowledge disclosure are salient to our analysis: secrecy, patenting, publishing and patent-paper pairs.

"Non-disclosure" or secrecy is an important potential disclosure strategy that may be preferred by some funders (particularly those in the private sector or government agencies funding particular types of research with national security implications). Far from being a modern practice, secrecy was widely used by individuals and families as a source of competitive advantage: In seventeenth century England, the Chamberlen family maintained the design of forceps as a secret for three generations thus ensuring their position as the leading (male) midwives of the era (Radcliffe 1947). Early funders of research particularly patrons also had a utilitarian motives for maintaining at least some of the discoveries that they funded a secret (David 2000) and 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 2000, p. 13). In later periods, researchers funded on botanical expeditions also maintain their plant specimens, drawings and maps as secrets for their wealthy commercial patrons (Stroup 1990; Schiebinger & 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

results of research performed in the UK centered on charges that the researchers at the University of East Anglia had "an unacceptable culture of secrecy."[5]

The more systematic role of secrecy in the funding of academic research (the focus on this paper) is less well understood because, of course, it exists at odds with the disclosure practices commonly associated with the scientific community. We will touch on the evidence for secrecy within academia as we examine the disclosure requirements of different funding sources. However, in broad strokes we have evidence that funders make few active provisions against *non-disclosure* – for example the National Science Foundation asks researchers to make best efforts in disclosure but has no formal requirements limiting secrecy. Conversely, industrial funders are more closely associated with attempts to enforce secrecy on the scientists they fund. 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, 2006)

To overcome this problem, disclosure relies upon a complex set of institutions to provide incentives for scientists and those who fund them to engage in knowledge production and disclosure (Dasgupta and David 1994). Two critical institutions enable and encourage the disclosure of scientific knowledge which is of immediate usefulness or of importance to long-run knowledge accumulation: the patent system - what we have termed *commercial science* and the system of publications that we have termed *open science* (Gans, Murray and Stern 2010).

For researchers working within academia, open science is the dominant institutional logic for disclosure: when knowledge is disclosed through scientific publication in the academic literature researchers are rewarded with kudos (Dasgupta and David 1994; David, 2008). In

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

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 (Merton1957). The third disclosure choice pertains to commercial science – disclosure in patents which, among other functions, provide 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 must disclose knowledge to the level that enables a person "skilled in the art" to replicate that knowledge and potentially build upon it.

The fourth disclosure strategy – patent-paper pairs - is widespread among academic scientists (using a variety of funding sources). For example, with funding from Geron Corporation, Professor James Thomson from the University of Wisconsin developed both monkey and then human embryonic stem cells, disclosed the research in the form of an academic publication but only a few weeks prior to publication, filed patents. However 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 funds to following the complex timing requirements to enable disclosure through patent-paper pairs.

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).

Disclosure Practices for Public Funders

If public funding agencies, particularly the Federal government, have, at times, been vague with regards to their expectations around the selection of research projects, their stipulations regarding the disclosure of the results of these projects is even less precisely defined. Overall there is a strong adherence to the notion of autonomy for the scientific community and a sensibility that "self-regulation" and the incentives for the system of academic publication will eventually ensure that knowledge production is indeed disclosed.

With regards to patenting the government regulations are more precise. For example, the National Science Foundation, along with most other US government agencies, have strict provisions for the patenting of inventions funded by the agency. These provisions are guided by the *Bayh-Dole Act* 1980 as outlined in the Federal Register ([35 U.S.C. § 200 et seq.]). Specifically, they note that:

> *Unless otherwise provided in the award, if this award is for experimental, developmental, or research work the following clause will apply":*
> *a. Definitions*
> *1. INVENTION means any invention or discovery which is or may be patentable or otherwise protectable under Title 35 of the USC…*
> *2. SUBJECT INVENTION means any invention of the grantee conceived or first actually reduced to practice in the performance of work under this award…*
>
> *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 non-exclusive, 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 disclosure subject inventions to the NSF within two months and to include in that notification information about other publications and manuscripts. This is the most salient element of the contractual regulation of Federal funding that requires

rather than expects disclosure although it is not clear that in practice this is always fulfilled and there is considerable discretion on the part of investigators:

> *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…*

With regard to the disclosure of research in other non-patent documents, the provisions are much less stringent and hold few obligations of disclosure. In particular, the NSF outlines only that:

> *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. It expects investigators to share with other researchers, at no more than incremental cost and within a reasonable time, the data, samples, physical collections and other supporting materials created or gathered in the course of the work. It also encourages grantees to share software and inventions or otherwise act to make the innovations they embody widely useful and usable.*
> *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.*

In contrast, the Medical Research Council in the UK has a somewhat different set of requirements with a greater emphasis on publication as a strong expectation:

> *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.*

There are also provisions for making such publications more widely available. Specifically, the UK's Medical Research Council has the following requirements:

> *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.*

In spite of these detailed provisions, few government funding agencies in the US and elsewhere have specific requirements to limit secrecy or to enforce disclosure except through the use of publications (and potentially patents) as a selection mechanism for future awards.[6] As a means of protection for academics against the strictures of private funding, contracts with the private sector place a greater emphasis on enabling (rather than requiring) disclosure.

Some foundations follow a similar line and, in fact, use disclosures – in particular, tangible disclosures – as measures of funding performance. 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."

However, as noted earlier, the Gates Foundation pursues a selection model that emphasizes immediate value as well as funding gaps with regard to both private and public sources. Alongside this its project performance criteria emphasize the statement of measurable performance outcomes: what they term 'actionable measurement.'[7] This embeds measurement as part of the grant selection process and appears to operate very much in a case-by-case manner. It places no specific requirements on disclosure and, instead, an evaluation of impact. Of course, these may well be related in practice; something we do not currently observe.

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

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

Disclosure Practices of Mission-Oriented Public Funders

The Disclosure Practices of Mission-Oriented Public Funders at times are subject to a variety of strictures regarding secrecy. Economists such a Joseph Stiglitz have argued that "that there should be a strong presumption in favor of transparency and openness in government".[8] Nonetheless, as Senator Moynihan pointed out in an address on Secrecy in Science to the AAAS in 1999[9], the Report of the Commission on Protecting and Reducing Government Secrecy (1997) begins: Secrecy is a form of government regulation. Americans are familiar with the tendency to overregulate in other areas. What is different with secrecy is that the public cannot know the extend or the content of regulation.[10]

With regards to publically funded research, it is through the **Invention Secrecy Act of 1951**[11] - a Federal legal provision – that Federal agencies can prevent the disclosure of new inventions that pose a potential national security threat. While only formalized in the 1950s, during World War I Congress authorized the USPTO to classify certain defense-relevant patent applications. Similarly throughout World War II, specifically with regards to research done as part of the Manhattan Project, patent secrecy was used to maintain secrecy over information considered critical to national security. After the 1951 Invention Secrecy Act was put into place, the formal process is that the Defense Agencies share with the PTO with a classified list of sensitive technologies in the form of the "Patent Security Category Review List" (PSCRL).[12] The formal language of the statute is informative:

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[8] Joseph Stiglitz, 1999 Oxford University Amnesty International Lecture, Oxford University, January 27, 1999 (transcript available at www.worldbank.org).

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

[10] 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.

[11] 35 U.S.C. § 181–188

[12] 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.

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 therefor 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.

More specifically, a secrecy order prevents patent award and orders that the invention be kept secret, restricts the filing of foreign patents, and specifies procedures to prevent disclosure of ideas contained in the application.[13][14] The number of patents treated in this way sits at just over 5,000 in 2009 with 103 new secrecy orders imposed on patents in 2009. [15]

While capturing the most draconian disclosure limitations, policies used by DARPA certainly speak to the contractual limits on disclosure that can be imposed by public funding agencies. All DARPA BAAs are composed of the same basic sections, however the details differ from office to office and announcement to announcement. The basic structure involves eight sections: a description of the research opportunity, information about the financial award, proposer and proposal eligibility information, application and submission information, application review information, award administration information, agency contacts, and other

[13] 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.

[14] See the Project on Government Secrecy at http://www.fas.org/sgp/othergov/invention/index.html

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

information (DARPA-BAA-10-35 2010, DARPA-RA-10-76 2010). Most of the obligations and requirements on intellectual property and publications put forth by DARPA can be found in three of these sections: financial award information, award administration information, and other information. The financial award information specifies whether the research is funded under basic research (6.1), applied research (6.2), advanced technology development (6.3), or some combination thereof. The award administration information details the publication and export control restrictions on the research, which often depend on the above research classification. Finally, the section entitled other information includes terms governing ownership of intellectual property.

The classification of research DARPA designates for the award is the largest single contributor to the existence or lack of publication and intellectual property restrictions. For example, here is the stock language from a BAA that does not target a specific research classification:

> *As of the date of publication of this BAA, DARPA cannot identify whether or not the work under this BAA may be considered 'fundamental research,' i.e., basic and applied research in science and engineering, the results of which ordinarily are published and shared broadly within the scientific community, as distinguished from proprietary research and from industrial development, design, production, and product utilization the results of which ordinarily are restricted for proprietary or national security reasons. Notwithstanding this statement of expectation, DARPA is not prohibited from considering and selecting research proposals that, while perhaps not qualifying as 'fundamental research' under the foregoing definition, still meet the BAA criteria for submissions. In all cases, the contracting officer shall have sole discretion to select award instrument type and to negotiate all instrument provisions with selectees (DARPA-BAA-10-35 2010).*

On the other hand, here is an example that has targeted basic and applied research:

> *As of the date of publication of this RA, DARPA expects that program goals for this RA may be met by proposers intending to perform 'fundamental research,' i.e. basic and applied research in science and engineering, the results of which ordinarily are published and shared broadly within the scientific community, as distinguished from proprietary research and from industrial development, design, production, and product utilization results of which ordinarily are restricted for proprietary or national security reasons. Notwithstanding the statement of expectation, DARPA is not prohibited from considering and selecting research proposals that, while perhaps not qualifying as*

> *'fundamental research' under the foregoing definition, still meet the RA criteria for submissions. In all cases, the contracting officer shall have sole discretion to select award instrument type and negotiate all provisions with selectees (DARPA-RA-10-76 2010).*

It is important to note that "in all cases, the contracting officer shall have sole discretion to select award instrument type and to negotiate all instrument provisions with selectees" (DARPA-BAA-10-35 2010, DARPA-RA-10-76 2010). Essentially, this allows DARPA to work around any contract provisions outlined in the BAA on a case-by-case basis. While publication restrictions are mentioned in the award information section, details are left to the award administration section.

All 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). This statement is followed by a definition of Contracted Fundamental Research, which I have transcribed below:

> *'Contracted Fundamental Research includes [research performed under] grants and contracts that are (a) funded by budget category 6.1 (Basic Research), whether performed by universities or industry or (b) funded by budget category 6.2 (Applied Research) and performed on-campus at a university. The research shall not be considered fundamental 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).*

Therefore all research performed on a university campus that is not classified by DARPA as advanced technology development will have no publishing restrictions. However, it is important to note "that DARPA may elect to award other instruments" even if university researchers propose a fundamental research project (DARPA-BAA-10-35 2010, DARPA-RA-10-76 2010). This means that DARPA can reclassify a proposal for fundamental research as advanced

technology development if it so chooses and subject the research to one of the publication restrictions shown below in Table 1. In addition, if the research moves beyond "fundamental research," it will be subject to United States export control regulations outlined in Appendix B.

Table 1. DoD Publication Restrictions

DoD Distribution Statement	Description
The below statement requires review through DISTAR	
A	Approved for public release; distribution is unlimited
The below statements are assigned by the sponsoring DARPA Program manager	
C	Distribution authorizes U.S. 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 U.S. 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 U.S. 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 U. S. 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 od determination). DoD Controlling Office is (insert).
F	Further dissemination only as directed by (insert DoD Controlling Office) (date of determination) or higher DoD authority.

(DARPA Distribution Statements 2010)

In the "other information" section of each BAA, DARPA outlines its policies regarding noncommercial and commercial technical data and computer software as well as patents and other forms of intellectual property as governed by the Defense Federal Acquisition Regulation Supplement (DFARS). Overall in the defense sector with funding from DARPA or other parts of DOD, the government occasionally reclaims intellectual property to further defense needs. More specifically, DARPA's policies further depend on whether the proposal is for a procurement or non-procurement contract. 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). Furthermore, the identification must be represented as two lists of the following form:

NONCOMMERCIAL or COMMERCIAL				
Technical Data Computer Software To be Furnished With Restrictions	Summary of Intended Use in the Conduct of the Research	Basis for Assertion	Asserted Rights Category	Name of Person Asserting Restrictions
(LIST)	(NARRATIVE)	(LIST)	(LIST)	(LIST)

(DARPA-BAA-10-35 2010). It is important to note that the Government assumes unlimited rights to any technical data and software not delineated in the above list. Proposers of non-procurement contracts are instructed to disclose similar information, primarily restrictions on Government use of technical data and software, but without as the restrictions on format outlined in DFARS subpart 227(DARPA-BAA-10-35 2010). All proposers are instructed to provide documentation proving "ownership of or possession of appropriate licensing rights to all patented inventions (or inventions for which a patent application has been filed)" as well as similar documentation for all other intellectual property "that will be utilized under [the] proposal for the DARPA program" (DARPA-BAA-10-35 2010). In addition, DFARS 227.303 gives patent rights to the contractor for all inventions discovered while under contract. It is important to note however that the DoD can still issue a patent secrecy order and seize the invention if it deems it necessary, however it is unlikely to abuse this power with research institutions as they have an ongoing mutually beneficial relationship.

DARPA's standard contractual obligations are relatively unrestrictive with respect to intellectual property ownership and the dissemination of information. Much of this has to do with the fact that the RDT&E sponsored by DARPA is in the most fundamental of the seven DoD activities: basic research, applied research, and advanced technology development. In fact, for all fundamental research there are no standard publication restrictions and the contractor has rights to all intellectual property developed during the research. It is important to note however, that these are standard terms, and in all BAAs there is language allowing the program director to negotiate any and all elements on a case-by-case basis.

Other less formal methods of restricting disclosure also seem to have taken place although as they lie outside the formal setting of the negotiation between researchers and those that fund them, they are strictly outside our model. Nonetheless they provide additional richness to the complex tensions surrounding disclosure of publically funded research. According to a 1999 address to the AAAS conference on Secrecy and Science held at MIT given by Herbert Foerstel, former Head of Branch Libraries at University of Maryland and board member of the National Security Archive, **"**from 1973 until the late 1980s, the FBI conducted a secret surveillance program within America's unclassified scientific libraries, including both public and university libraries. That program, known as the Library Awareness Program, had [as one of its] two goals: To restrict access by foreign nationals, particularly Soviet and East Europeans, to unclassified scientific information".[16]

Disclosure Practices for Private Funders

The challenge of secrecy as a (non) disclosure outcome is particularly pressing for projects funded by industry within universities. In current medical science for example, secrecy

[16] Last accessed from http://www.aaas.org/spp/secrecy/Presents/foerstel.htm on 9-23-2010.

appears to be widespread. In a survey of more than 2000 life scientists at the 50 U.S. universities receiving the most National Institutes of Health funding, Blumenthal et al. (1996) found that more than 25% of the most productive researchers received industry funding although with some variation between clinical and non-clinical researchers: A significantly greater proportion of those in clinical departments (36 percent) compared to researchers in nonclinical departments (21 percent) reported receiving industrial funds. The precise disclosure requirements required of these recipients is not known, however, overall they produce statistically significantly more publications (although this does not imply more disclosure per unit of knowledge production). The authors also 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 (14.5 percent vs. 4.7 percent) thus suggesting more limited disclosure linked to industrial funding (this figure rises to over 17% for the subset of over 500 researchers whose area of focus is in biotechnology – including recombinant DNA, monoclonal antibodies and gene sequencing and compares to 12% for a similar sample of industrial funding recipients surveyed in 1985 (Blumenthal et al. 1986)[17]. This is also combined with more patenting disclosure, as illustrated in Table X (reproduced from Table 3 in Campbell et al. 1996, p. 1737).

[17] Blumenthal D, Gluck M, Louis KS, Stoto MA, Wise D. University-industry research relationships in biotechnology: implications for the university. Science 1986;232:1361-6.

TABLE 3. COMMERCIAL OUTCOMES OF RESEARCH BY LIFE-SCIENCE FACULTY MEMBERS ACCORDING TO TYPE OF OUTCOME.*

INDUSTRIAL SUPPORT	OUTCOME OF RESEARCH						
	APPLIED FOR PATENT	PATENT ISSUED	PATENT LICENSED	TRADE SECRET	PRODUCT UNDER REVIEW	PRODUCT ON MARKET	NEW COMPANY
	percent of respondents						
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

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

Concerns over secrecy and other delays in disclosure are particularly salient in medical research because of the close relationships between medical scientists and industry funders. In a second survey of more than 3000 physicians in specialties as diverse as general surgery, cardiology, anesthesiology and pediatrics, 94% of respondents reported that they had relationships with pharmaceutical companies including everything from food, to reimbursement for conference participation to payments for giving lectures or enrolling patients into clinical trials (Campbell et al. 2007). While relationships are not focused specifically on funding for research and therefore are less centrally the focus on this paper there is some (albeit limited) evidence to suggest that funding and other industry relationships may have an adverse impact on disclosure (Nathan and Weatherall 2002). Disclosure issues are particularly salient for researchers whose projects are funded by industry. In several cases, scientists have accused their funders of attempting to limit disclosure particularly of negative clinical results (Haack

2006).[18]

Among the most infamous cases is the relationship between Nancy Olivieri, a clinical researcher at the Hospital for Sick Children (Toronto) and the University of Toronto, and Apotex, a Canadian manufacturer of generic drugs who funded a short-term, uncontrolled clinical trial of deferiprone in patients with thalassemia who had iron overload (Oliveri et al. 1995)[19]. As leading physicians and 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).* The Oliveri case by no means the only example of the complex relationship between researchers, their funders and the universities (and medical schools) who serve as the intermediaries in the constructing and executing these contracts and whose role it is to enable effective and appropriate levels of disclosure.[20]

Another well-known dispute between biotechnology company Immune Response Corporation and scientific researchers, is described the thus: *"A drug company funds a large-scale clinical trial of its new AIDS therapy; when the results are unfavorable, the company tries to prevent their being published; when the researchers go ahead with publication anyway, the company seeks millions of dollars in damages" (Haack, p 47).* The research, conducted by Dr. James Kahn of the University of California, San Francisco (UCSF) and Dr. Stephen Lagakos of Harvard University was focused on Remune - an AIDS therapy "based on whole HIV particles,

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[18] Haack, Susan, Scientific Secrecy and Spin: The Sad, Sleazy Saga of the Trials of Remune. Law and Contemporary Problems, Vol. 69, 2006; University of Miami Legal Studies Research Paper No. 2007-02 . Available at SSRN: http://ssrn.com/abstract=938485

[19] Olivieri NF, Brittenham GM, Matsui D, et al. Iron-chelation therapy with oral deferiprone in patients with thalassemia major. N Engl J Med 1995;332:918-922.

[20] Kern D, Crausman RS, Durand KT, Nayer A, 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.] Davidoff F. New disease, old story. Ann Intern Med 1998;129:327-328. [Erratum, Ann Intern Med 1999;130:246.] Rennie D. Thyroid storm. JAMA 1997;277:1238-1243. [Erratum, JAMA 1997;277:1762.]

stripped of a protein called gp120, and killed by irradiation and chemical treatment.21" In the aftermath of a failed and halted phase I clinical trial, the leading scientists conducting the trial were told by the corporate sponsor that they should not continue to analyze and attempt to publish data from the trial.[22] When the academic researchers published a paper based on some (but not all of the trial data – some of the final data was unavailable to them), it was accompanied by an editorial in the *New England Journal of Medicine* on conflict of interest arguing that "the integrity of the research process must be protected and preserved."[23]

Of course, for-profit corporations are not alone in seeking to prevent the disclosure of potentially damaging scientific information (at least damaging from the perspective of the funder). For example, in Soviet-era Russia the government went to considerable lengths to prevent knowledge disclosure and dissemination.[24] However as one commentator on the Remune debacle noted: "[t]he intense pressure on individuals at academic institutions to publish and on the sponsoring companies to get their drugs on the market sometimes produce[s] tensions between the 2 parties, and if results are not favorable, disagreements can develop[,] leading to disputes, innuendos, and even legal action."[25] A large amount of editorializing has ensued regarding the role of corporate funding of academia particularly within the large and ever expanding academic medical centers that are increasingly reliant not on endowment funding but on Federal and corporate funding to support a large research base. Haack illustrates the point quoting from an editorial in *Nature Immunology* arguing that although "clinical trials sponsored by a product's developer are inherently conflicted[,] … industry funding is necessary,

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[21] Paul Smaglik, Reservoirs Dog AIDS Therapy, 405 NATURE 270, 272 (2000).

[22] Penni Crabtree, Scientists Say Firm Tried to Gag Them; Tell of Releasing AIDS Vaccine Data, SAN DIEGO UNION-TRIBUNE, Nov. 7, 2000, at B1 (as cited in Haack p. 56)

[23] Catherine D. DeAngelis, Conflict of Interest and the Public Trust, 284 J. AM. MED. ASS'N 2237, 2238 (2000).

[24] VALERY N. SOYFER, LYSENKO AND THE TRAGEDY OF SOVIET SCIENCE (Leo Gruliow & Rebecca Gruliow trans., 1994).

[25] Donald M. Poretz, Letter to the Editor, Outcomes of a Trial of HIV-1 Immunogen in Patients with HIV Infection, 285 J. AM. MED. ASS'N 2192, 2192–93 (2001).

as public funding for clinical research is inadequate."[26] More pragmatic is the voice from leading journal *Nature Biotechnology* which 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?"[27]

Of course much of the debate is actually grounded in the contracts that are signed between academic scientists and those who private corporations who fund them. Certainly, scandals, such as those experienced in academic medical centers, have exacerbated the need for clearer rules. These contractual provisions are rarely established via a bilateral agreement between researcher and funder within today's major research universities. More typically the negotiation is carried out and the contract signed by an "Office of Sponsored Projects" which reports to the university administration and seeks to represent the broader interests of the university in maintaining the disclosure of research findings.

Negotiations are particularly intense and complex with regards to funding from industry. While early examples of industry contracts gave many of the rights to the knowledge produced to the funder (usually referred to as the sponsor), with the growing emphasis on the role of the university as the producer of knowledge for the public domain, universities have become more sensitive to charges of "contract research" 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 2008; Sampat et al. 200x; XXX) the ways in which universities and university researchers contract over the incoming funding (rather than the outgoing licensing of completed projects) is poorly understood. We have little systematic knowledge of the

[26] Editorial, Collaborative Conflicts, 1 NATURE IMMUNOLOGY 449 (2000). 114
[27] Editorial, Knee-Jerk Response, 18 NATURE BIOTECHNOLOGY 1223 (2000)

disclosure provisions put into place for privately (commercially) sponsored research.

To fill this gap, we have gathered some preliminary data in this regard which catalogues the practices of 20 major research universities within the United States as of June 2009.[28] We examined standard intellectual property terms offered to industrial sponsors in single sponsor research agreements with regard to publications, rights in tangible research property, university project inventions, university copyrightable software and databases and university copyrightable works other than software. While all of the above terms were not addressed by each university in the sample, terms are consistent across schools and departments within each university. However, there 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.

Sixteen of the twenty universities in our sample explicitly address publication restrictions in single sponsor research agreements with industrial entities.[29] Within these agreements we examined 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 in publication. We present Article VI of the research contract used by the University of California at Berkeley below as an example of common terms presented to industrial sponsors with regard to publications.

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[28] The 20 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.

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

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 allow full disclosure in all contracts and the University of Texas at Austin allows full disclosure if it has exclusive rights to the intellectual property produced in the project, but gives the sponsor the right to mark information as confidential and unpublishable if the sponsor has some claim to the intellectual property produced. Nonetheless, every university permits pre-sponsor publication review even though the sponsor may not necessarily have rights to restrict the information divulged in the publication. The majority of universities gave the sponsor 30 days for review and allowed between a 30 day and 60 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-month extension. Only one quarter of universities in our sample exempt theses and dissertations from these review periods. Interestingly, these were not the universities with exceptionally long review periods. Three quarters of the universities in our sample do not specify the terms of sponsor acknowledgment, a minority allow the sponsor to elect whether or not it wishes to be acknowledged and Cornell is the only university to automatically acknowledge sponsors in the publication. This heterogeneity across universities is surprising and merits further investigation into its causes and effects.

Commercialization and Patenting Restrictions

While the terms surrounding publications are heterogeneous across universities, the terms governing rights in tangible research property are dichotomous. We examined whether standard contract agreements provide disposition for rights in tangible research property and the terms of those rights, if provided, in 11 of the twenty research universities.[30] Six of the universities do not specify such rights, four do, and the terms Johns Hopkins University offers vary within the university. When addressed, the university is always given the right to use all tangible research property and ownership rights generally required further negotiations and/or separate agreement. Harvard was the only university to claim ownership rights over the research property and only give the sponsor rights for internal research use. While the 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, the terms governing university project inventions are nearly uniform across the 11 universities. We recorded which party is awarded ownership of inventions, whether internal research licenses are offered to the non-owning 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 contract used by the Massachusetts Institute of Technology below as an example of common terms presented to industrial sponsors with regards inventions.

[30] The 11 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.

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.

B. LICENSING OPTIONS. For each MIT Invention on which a patent application is filed by MIT, MIT hereby grants the Sponsor a non-exclusive, 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 above, the university retains ownership of all project inventions in each case. 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 non-sublicensable 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 non-sublicensable. The time given to sponsors to elect licenses when available range from one to six months with an average of three months. The additional time given to negotiate such licenses ranges from three to six months with an average of three months. The greatest variability in the terms regarding university project inventions is whether the sponsor is required to reimburse expenses. This requirement is imposed on sponsors in just over half of the examined universities, while it is a negotiable item in the majority of those in which it is not required.

As with university project inventions, the terms governing the ownership and licensing of University copyrightable software and databases are consistent across 10 examined universities.[31] We recorded whether or not the university claims ownership over the work, a license for internal research use is offered to the sponsor, the existence and nature of any commercial licenses and the time given to elect such licenses. We present an excerpt from Section 9 of the research contract used by Stanford University as an example of common terms presented to industrial sponsors with regard to copyrightable software and databases.

> 9.8 **Copyright Licenses**. Sponsor may elect to negotiate a nonexclusive or exclusive (subject to third party rights, if any) royalty-bearing license to use, reproduce, display, distribute and perform computer software and its documentation for commercial purposes in a designated field of use. Sponsor must elect within 3 months of notice of Technology disclosure of copyrightable material. Computer software for which a patent application is filed is subject to Paragraph 9.4.
>
> 9.9 **Non-Election.** If Sponsor does not provide written notice to Stanford within 3 months of a written disclosure under Paragraph 9.4, 9.6 or Section 9.8, Stanford has no further obligations to the Sponsor and may license the Stanford Technology to third parties.

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

9.10 **Assignment.** Stanford represents that all of its employees, students, and consultants who participate in the Research Program will be obligated to assign to Stanford all their rights in patentable or copyrightable Technology.

As observed in Stanford's agreement above, universities claim ownership rights in all examined contracts except those of Johns Hopkins University, which usually retain the rights for Johns Hopkins. The majority of universities offer NERFs for the sponsor's internal use and such licenses are negotiable for those that do not. With regard to commercial licenses, the majority of terms across universities are negotiable and situation dependent ranging from royalty bearing licenses to NERFs. In addition, sponsors are given between two and six months to elect licenses when given or negotiated.

Unlike copyrightable software and databases, the terms governing other copyrightable works are more heterogeneous across the 10 universities. As with software and databases, we examined whether the university retains ownership of the work, internal research licenses are offered to the sponsor, the existence and nature of commercial licenses as well as the time to elect in time to negotiate such licenses. Except for the University of Arizona, which allocates ownership to the investigator, all examined universities retained ownership of the copyrightable work. The most common license given to sponsors for internal research only covers explicit deliverables, however a minority of universities offer such licenses on all copyrightable work produced under sponsorship. Commercial licenses are not generally offered, and when they are, they are in the form of a NERF. The majority of universities in our sample do not specify a time limit on the election or negotiation of such licenses. However, when specified, sponsors are given 60 days to elect a commercial license and the hundred and 80 days to negotiate the terms of that license with the university.

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

The previous two sections illustrated the selection intentions as well as the conditions that public funders place on research projects. Specifically, for the most part, funders select projects on the basis of scientific merit rather than immediate applications. 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 also can 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 and how funding conditions impact the number, mix and openness of projects funded overall. Consequently, we see this theoretical exercise as a critical first step towards 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. With regard to selection, we assume, initially, that it is difficult for the funder to observe immediate applicability while they can more readily evaluate scientific merit. We do, however, analyze what happens when funders can observe more. With regard to disclosure, the evidence above

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.

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.[32] Projects differ in terms of their potential immediate social benefit, *v*, and their potential present value of future scientific benefits, *b*. *b* and *v* are independently and identically distributed, uniformly on [0,1].

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 $\mu \in [2\beta, 1-\delta]$.

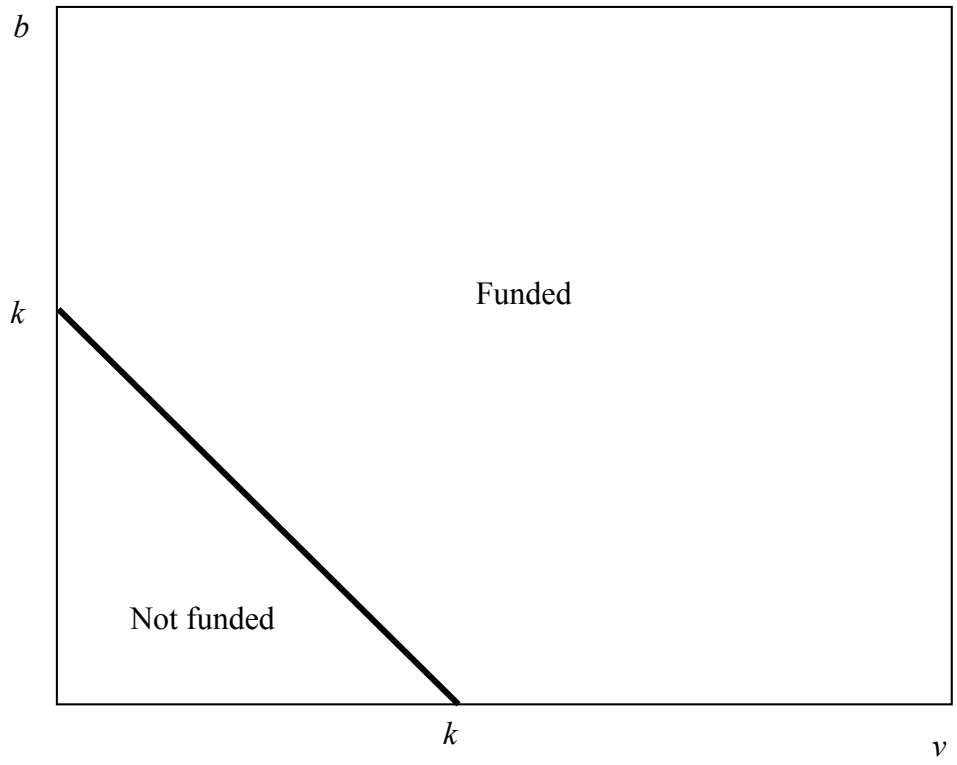
With regard to scientific benefit, *b* is realized if and only if research outcomes are publicly disclosed (i.e., the scientist engages in disclosure via publishing). Otherwise, there are no scientific benefits. It is assumed that the scientist appropriates *b* in 'kudos' if the project proceeds and 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 under conditions where all

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

projects for which $v+b \geq k$ are funded while those with $v+b < k$ do not proceed (Figure 1).

Figure 1: Optimal Funding



Intellectual Property and Competition

For simplicity, we assume that at most two firms can commercialize the outcome of a given research project. 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, $d < 1 - \beta v$.[33]

If it is 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

[33] Below 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.

blocked. There are many ways this might be modeled. Here we assume that, if there is a patent, with probability 1 – ρ, 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 $\mu v - (1-\rho)(\beta v + d)(\mu - \beta)v$ if there is disclosure of scientific knowledge and $\mu v - (1-\rho)\beta v(\mu - \beta)v$ otherwise.[34] In what follows, we use a variable, *i*, to indicate whether a firm as a patent (*i* = 1) or not (*i* = 0).

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.[35] However, publication may increase joint surplus if $b > (1 - i\rho)d(\mu - \beta)v$. In this case, provided that profits are still non-negative 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

[34] 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.

[35] 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.

capital costs.

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, to ensure that the commercial profits cover capital costs as these cannot be funded elsewhere as the scientist is assumed to have no money. 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,

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

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

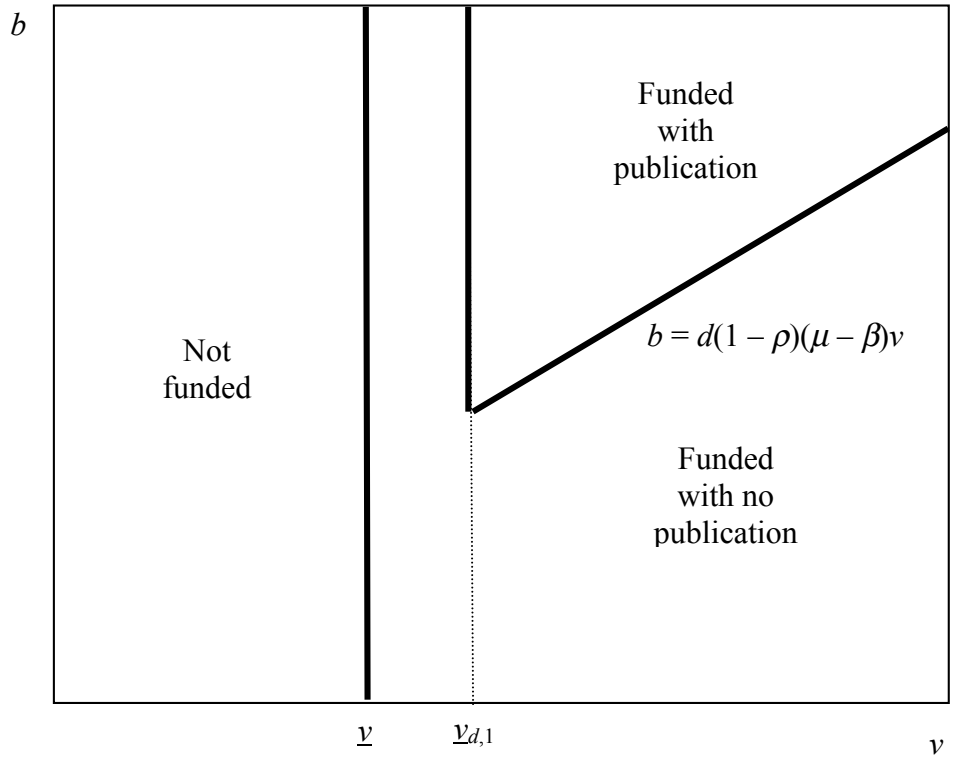
those projects will enable the project to cover capital and scientist costs.

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 2 depicts the equilibrium outcome. Importantly, projects that have both a high future and immediate value are more likely to be funded and also more likely to be disclosed through publication. These are projects that 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.

Figure 2: 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 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.

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 ($b + v$). However, 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 and hence, cannot predict whether the project might otherwise receive private funding. 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. Scotchmer and Maurer (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 examine below 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 $b > \underline{b}$.[36] 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 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, that the scientist cannot profit from commercialization and that no patent is allowed to be taken out. This is a common requirement from funding by government sources. Second, that the scientist can profit from commercialization but that 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.

[36] 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.

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* $b \geq \mu v - (1-\rho)\beta v(\mu - \beta)v - k$ *; or*

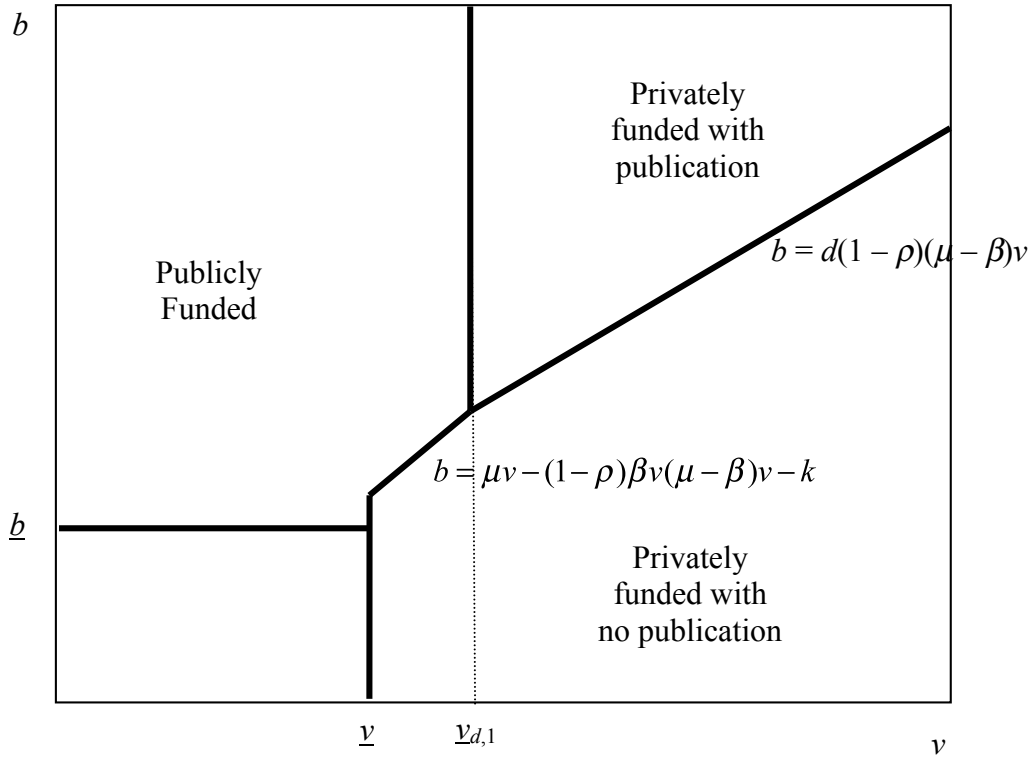
A research project (b,v) *will be privately funded with publication if* $v \geq \underline{v}_{d,1}$ *and* $b > d(1-\rho)(\mu - \beta)v$. *A research project* (b,v) *will be privately funded without publication if* $v \geq \underline{v}$ *and* $b < \mu v - (1-\rho)\beta v(\mu - \beta)v - k$.

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 3. 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 some projects the public funder would like to fund in order to generate scientific benefits from publication but 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.

Figure 3: Public Funding (No Commerce/No Patent)



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 or not and also the type of funding those projects receive – those remain private.

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.[37] The following proposition summarizes the resulting equilibrium.

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

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* $b \geq (\rho\beta v + d)(\mu - \beta)v - k$ *; or*

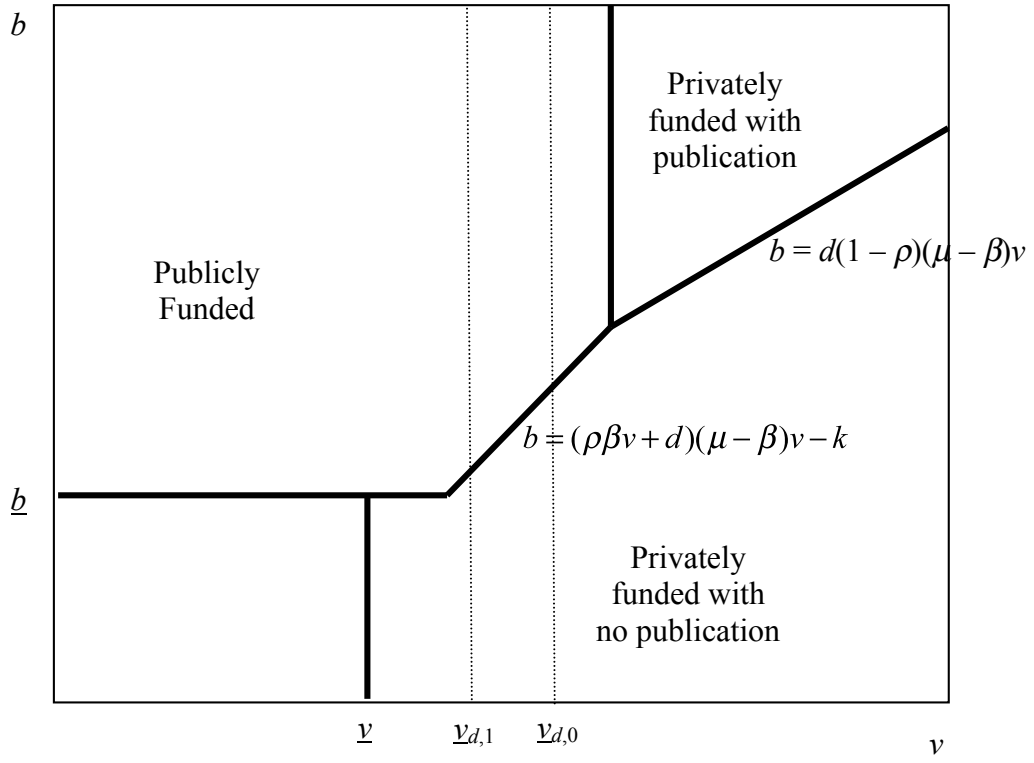
A research project (b,v) *will be privately funded with publication if* $v \geq \frac{1}{2\beta}\left(\sqrt{d^2 + \frac{4k\beta}{(\mu-\beta)\rho}} - d\right)$ *and* $b > d(1-\rho)(\mu-\beta)v$. *A research project* (b,v) *will be privately funded without publication if* $v \geq \underline{v}$ *and* $b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

The proof follows from that fact that:

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

A possible outcome is depicted in Figure 4. 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.

Figure 4: Public Funding (Commerce/No Patent)



It is useful to compare this outcome to a weaker restriction – that a patent can be taken out but it should be licensed openly.[38] The idea here is to increase the probability that there is competition and 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 $\mu v - (\beta v + d)\left((\mu - v)v - \frac{1}{2}(\beta v + d)\right)$. This makes it more likely that the firm would accept

[38] DISCUSS NAS REPORT.

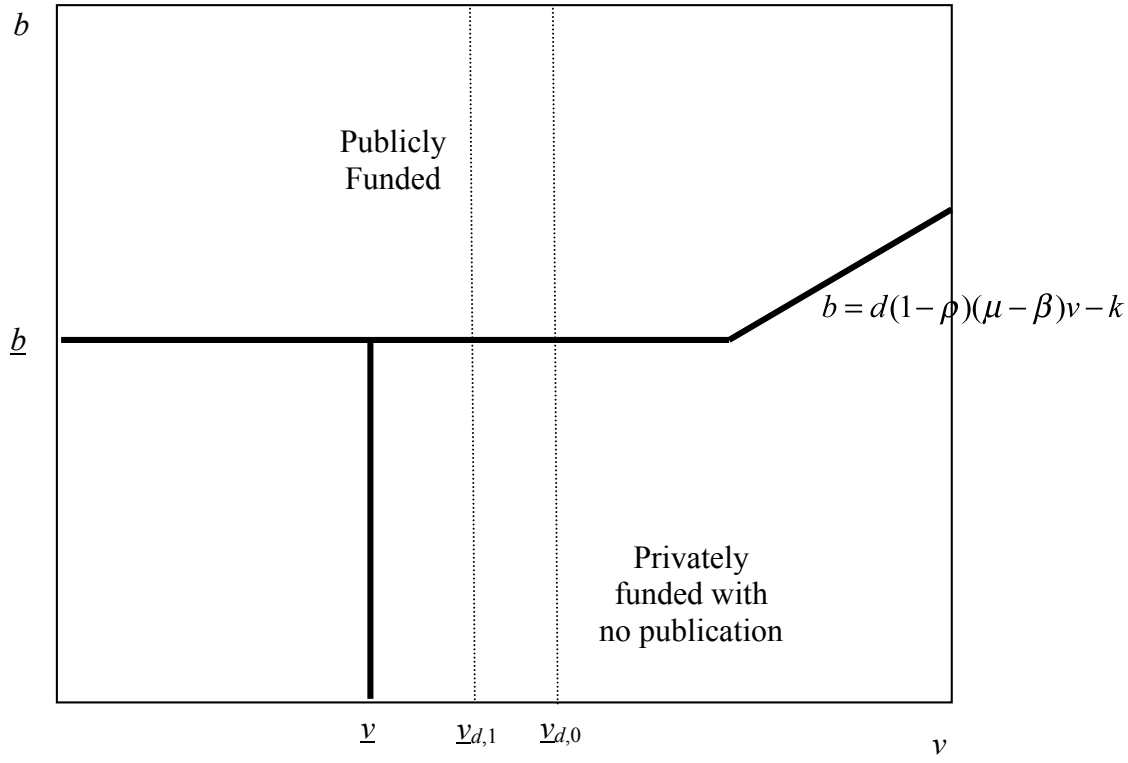
public funding but significantly makes the firm less concerned about the impact of disclosure requirements on its profits.

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 5 depicts a possible outcome.

Figure 5: Public Funding (No restrictions)



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. 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 no 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.

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 following this, their employers did with a likely sharing of benefits in non-monetary 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 et.al., 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 (Henderson, Jaffe and Trajtenberg, 1998) 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, such an evaluation has not yet been conducted.

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 aspect 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).

What this means is that, comparing a 'no commercial payment' situation to a pure privately funded situation, there would be research projects that 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 of this, however, 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 the research funded federally but performed in their home institutions. Instead, each emphasizes the role of competition in promoting more efficient search and commercialization from Universities.

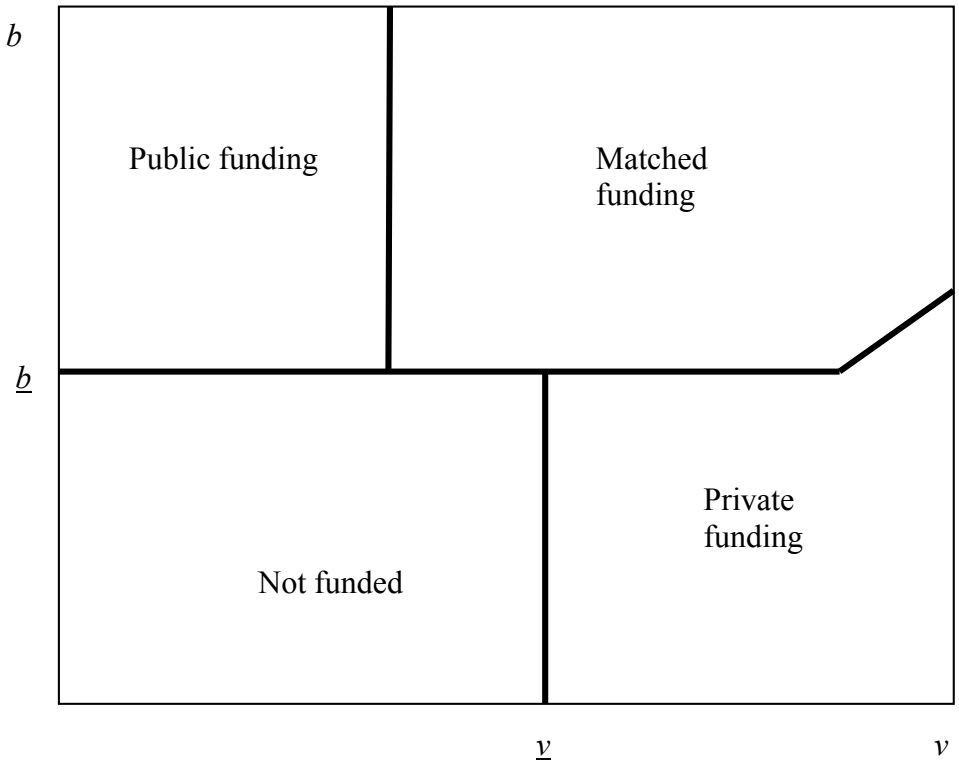
Placing weight on immediate value in selection

Thusfar, we 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. Instead, if the funder could also observe immediate application value, then it could commit not to funding projects that had both high scientific and immediate value and 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, Scotchmer and Maurer (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 case, public funders would offer researchers a menu of options. A possible outcome of this is depicted in Figure 6.

Figure 6: Mixed Funding Rules



In Figure 6, 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 who 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.

5. An Agenda for Research

This paper highlights a number of critical trade-offs that public funders must confront when supporting research projects. Even where their support is directed towards projects with high scientific value, the funder's choice of disclosure requirements and commercialization restrictions impact on the portfolio of projects that will be attracted by the support i.e. 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, 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 empirical survey notes that selection criteria tend to have common claims based on measurable scientific

outcomes across funding organizations but reveal less explicit acknowledgement of wider impacts and highly variable commitments to these the desirability of these impacts. In contrast, the growing not-for-profit foundation sector, in an attempt to differentiation themselves from purely public funders, have 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 – a trend that is changing in the context of foundations who are also coming more aggressive regarding their disclosure and commercialization conditions but will a limited framework of analysis with which to adjudicate these requirements. Finally, we observed that commercialization outcomes have been considered with explicit concern for conflicts of interest as well as facilitating diffusion of scientific ideas but that little attention has been directed as to whether these restrictions have adversely impacted on the distribution of public funds as well as generated real improvements in overall 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 more changes in commercialization opportunities impact on 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 level 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 paper 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 weaken intellectual property protection's role in facilitating scientific openness. If an area where open licensing emerged as an 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 paper 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 a necessary one to understand some of the new trade-offs exposited in this paper.

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Appendix A (DOD Financial Management Regulation 2008)

"Budget Activity 1, Basic Research.

Basic research is systematic study directed toward greater knowledge or understanding of the fundamental aspects of phenomena and of observable facts without specific applications towards processes or products in mind. It includes all him scientific study and experimentation directed toward increasing fundamental knowledge and understanding in those fields of the physical, engineering, environmental, and life sciences related to long-term national security needs. It is farsighted high payoff research that provides the basis for technological progress. Basic research may lead to: (a) subsequent applied research and advanced technology developments in Defense-related technologies, and (b) new and improved military functional capabilities in areas such as communications, detection, tracking, surveillance, propulsion, mobility, guidance and control, navigation, energy conversion, materials and structures, and personnel support. Program elements in this category involve pre-Milestone A efforts.

Budget Activity 2, Applied Research.

Applied research is systematic study to understand the means to meet a recognized and specific need. It is a systematic expansion and application of knowledge to develop useful materials, devices, and systems or methods. It may be oriented, ultimately, toward the design, development, and improvement of prototypes and new processes to meet general mission area requirements. Applied research may translate promising basic research into solutions for broadly defined military needs, short of system development. This type of effort may vary from systematic mission-directed research beyond that in Budget Activity 1 to sophisticated breadboard hardware, study, programming and planning efforts that establish the initial feasibility and practicality of proposed solutions to technological challenges. It includes studies, investigations, and non-system specific technology efforts. The dominant characteristic is that applied research is directed toward general military needs with a view toward developing and evaluating the feasibility and practicality of proposed solutions and determining their parameters. Applied Research precedes system specific technology investigations or development. Program control of the Applied Research program element is normally exercised by general level of effort. Program elements in this category involve pre-Milestone B efforts, also known as Concept and Technology Development phase tasks, such as concept exploration efforts and paper studies of alternative concepts for meeting a mission need.

Budget Activity 3, Advanced Technology Development (ATD).

This budget activity includes development of subsystems and components and efforts to integrate subsystems and components into system prototypes for field experiments and/or tests in a simulated environment. ATD includes concept and technology demonstrations of components and subsystems or system models. The models may be form, fit and function prototypes or scaled models that serve the same demonstration purpose. The results of this type of effort are proof of technological feasibility and assessment of subsystem and component operability and producibility rather than the development of hardware for service use. Projects in this category have a direct relevance to identified military needs. Advanced Technology Development demonstrates the general military utility or cost reduction potential of technology when applied to different types of military equipment or techniques. Program elements in this category involve pre-Milestone B efforts, such as system concept demonstration, joint and Service-specific experiments or Technology Demonstrations and generally have Technology Readiness Levels of 4, 5, or 6. Projects in this category do not necessarily lead to subsequent development or procurement phases, but should have the goal of moving out of Science and Technology (S&T) and into the acquisition process within the future years defense program (FYDP). Upon successful completion of projects that have military utility, the technology should be available for transition.

Budget Activity 4, Advanced Component Development and Prototypes (ACD&P).

Efforts necessary to evaluate integrated technologies, representative modes or prototype systems in a high fidelity and realistic operating environment are funded in this budget activity. The ACD&P phase includes system specific efforts that help expedite technology transition from the laboratory to operational use. Emphasis is on proving component and subsystem maturity prior to integration in major and complex systems and may involve risk reduction initiatives. Program elements in this category involve efforts prior to Milestone B and are referred to as advanced component development activities and include technology demonstrations. Completion of Technology Readiness Levels 6 and 7 should be achieved for major programs. Program control is exercised at the program and project level. A logical progression of program phases and development and/or production funding must be evident in the FYDP.

Budget Activity 5, System Development and Demonstration (SDD).

SDD programs have passed Milestone B approval and are conducting engineering and manufacturing development tasks aimed at meeting validated requirements prior to full-rate production. This budget activity is characterized by major line item projects and program control is exercised by review of individual programs and projects. Prototype performance is near or at planned operational system levels. Characteristics of this budget activity involve mature system development, integration and demonstration to support Milestone C decisions, and conducting live fire test and evaluation and initial operational test and evaluation of production representative articles. A logical progression of program phases and development and production funding must be evident in the FYDP consistent with the Department's full funding policy.

Budget Activity 6, RDT&E Management Support.

This budget activity includes research, development, test and evaluation efforts and funds to sustain and/or modernize the installations or operations required for general research, development, test and evaluation. Test ranges, military construction, maintenance support of laboratories, operation and maintenance of test aircraft and ships, and studies and analyses in support of the RDT&E program are funded in this budget activity. Costs of laboratory personnel, either in-house or contractor operated, would be assigned to appropriate projects or as a line item in the Basic Research, Applied Research, or ATD program areas, as appropriate. Military construction costs directly related to major development programs are included.

Budget Activity 7, Operational System Development.

This budget activity includes development efforts to upgrade systems that have been fielded or have received approval for full rate production and anticipate production funding in the current or subsequent fiscal year. All items are major line item projects that appear as RDT&E Costs of Weapon System Elements in other programs. Program control is exercised by review of individual projects. Programs in this category involve systems that have received Milestone C approval. A logical progression of program phases and development and production funding must be evident in the FYDP, consistent with the Department's full funding policy."

Appendix B (DARPA-BAA-10-35 2010)

"The Contractor shall comply with all U. S. export control laws and regulations, including the International Traffic in Arms Regulations (ITAR), 22 CFR Parts 120 through 130, and the Export Administration Regulations (EAR), 15 CFR Parts 730 through 799, in the performance of this contract. In the absence of available license exemptions/exceptions, the Contractor shall be responsible for obtaining the appropriate licenses or other approvals, if required, for exports of (including deemed exports) hardware, technical data, and software, or for the provision of technical assistance.

The Contractor shall be responsible for obtaining export licenses, if required, before utilizing foreign

persons in the performance of this contract, including instances where the work is to be performed on-site at any Government installation (whether in or outside the United States), where the foreign person will have access to export-controlled technologies, including technical data or software.

The Contractor shall be responsible for all regulatory record keeping requirements associated with the use of licenses and license exemptions/exceptions.

The Contractor shall be responsible for ensuring that the provisions of this clause apply to its subcontractors."

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