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Simultaneous pursuit of discovery and invention in the US Department of Energy

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ABSTRACT

There is a sharp boundary between basic and applied research in the organizational structure of the US Department of Energy (DOE). In this work, we consider a branch of DOE that was designed to operate across this boundary: the Advanced Research Projects Agency – Energy (ARPA-E). We hypothesize that much of energy research cannot be neatly categorized as basic or applied and is more productive outside of the confines of the basic/applied dichotomy; ARPA-E gives us an opportunity to test that hypothesis. We construct a novel dataset of nearly 4000 extramural financial awards given by DOE in fiscal years 2010 through 2015, primarily to businesses and universities. We collect the early knowledge outputs of these awards from Web of Science and the United States Patent and Trademark Office. Compared to similar awards from other parts of DOE, ARPA-E awards are significantly more likely to jointly produce both a publication and a patent. ARPA-E has been highly productive in creating new technology, while also contributing new scientific knowledge. This observation points to the productive overlap of science and technology in energy research and, more generally, for mission-oriented research funding organizations.

1. Introduction

There is a long-running debate over the role of government in funding applied research. There is a clear public need for advancement in technology areas such as energy and healthcare, and yet the use of public funds to influence private markets is controversial. One effect of this debate has been the sectioning off of basic and applied research funding streams, despite increasing awareness that the conceptual boundary between these two categories is artificial.

The US Department of Energy (DOE) in particular is organized around a sharp dividing line between basic and applied research, such that nearly all research funding programs are categorized as exclusively one or the other. In the past decade, however, DOE has undergone a number of changes, including the creation of an agency called Advanced Research Projects Agency – Energy (ARPA-E) to accelerate "transformational technological advances" in energy (110th Congress, 2007). The creation of ARPA-E offers a rare opportunity to study the relationship between basic and applied energy research funding, as it appears to operate across the boundary between the two. In this paper, we compare ARPA-E projects to those funded by other parts of DOE, and we ask whether there is more or less knowledge produced from the union of science and technology at ARPA-E.

Many stories of major advances in technology provide qualitative evidence that basic and applied research efforts are complementary, with the discovery of new phenomena and the invention of new technology occurring hand-in-hand. Documented examples of breakthroughs from major industrial research centers of the past, such as Bell Labs, Xerox, and PARC, depict research that was driven simultaneously by curiosity and a desire to advance practical applications (Gertner, 2012). Still, some questions remain: Does this synergy between basic and applied research also exist in the context of modern scientific research, which is conducted primarily with government funds at universities and government-owned laboratories? And does its effectiveness reach beyond isolated examples to improve the productivity of research funding institutions in aggregate?

These are interesting theoretical questions, as well as important questions of contemporary innovation policy. In the US, the existence of ARPA-E and mission-oriented research in general is threatened by the perception that government's proper role is only to fund basic research (Anadón et al., 2017; Narayanamurti, 2017). And as governments worldwide fulfill their Mission Innovation commitments and devote more public funds to energy innovation, it will be increasingly

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important to understand how research institutions can achieve transformative impact. Past and present institutional experiments must be evaluated in order to improve the effectiveness of future energy innovation spending (Chan et al., 2017).

We find that, in its first six years of operation, ARPA-E was highly effective in producing patents and publications. Projects funded by ARPA-E were significantly more likely to do research that was both published and patented than their counterparts elsewhere in DOE. From this, we infer that scientific discovery is not strictly the domain of basic research programs, and the isolation of basic research represents a missed opportunity for creating useful knowledge. If the intersection of basic and applied research increases the rate of knowledge production at DOE, this implies the need to reconsider the organizing principle for the department, which spends billions of dollars on R&D each year.[2]

In the next section, we review the division between basic and applied research at DOE and the role of ARPA-E. In Section 3, we describe our empirical approach of assessing research funded by different parts of DOE, and Section 4 provides the quantitative results of our analysis. The final sections of the paper discuss the implications of these results for R&D funding programs.

2. Background

2.1. The false dichotomy between basic and applied research

Vannevar Bush, in his famous report recommending the creation of the National Science Foundation, described two types of research: basic research, which "is performed without thought of practical ends," and applied research, which is the application of knowledge to practical purposes (Bush, 1945). This vision of research as an activity that can be neatly categorized as either "basic" or "applied" in nature was highly influential. In the years since, however, many scholars of science and technology have found that is not useful to distinguish between "basic" and "applied" research on the basis of the researcher's intentions (Rosenberg, 1990; Stokes, 1997). Investigations that aim to serve a particular purpose may yield unexpected scientific discoveries, while researchers that aim to explore new phenomena often end up inventing new technology. There have been many instances of overlapping discovery and invention in the development of information technology (Narayanamurti et al., 2013) and other fields (Narayanamurti and Odumosu et al., 2016).

Some research funding agencies, especially those that serve an industry with a public customer such as space or defense, are organized to reflect the complementarity between curiosity-driven and application-driven research. Most notably, the Defense Advanced Research Projects Agency (DARPA) has contributed to many technological advances, using a "connected science model" to operate across the barrier between basic and applied research (Bonvillian, 2009). Elsewhere in the Department of Defense (DOD), the entire spectrum of R&D activities is integrated within each of several organizations, including the Army, Navy, Air Force, and multiple defense agencies. Indeed, the Defense Science Board Task Force on Basic Research specifically recommended against centralizing basic research, stating that, "any potential savings, or other supposed benefits, that might accrue from such a restructuring would be far outweighed by distancing basic research from applied research and from the military operators" (Defense Science Board, 2012). Even the NSF has recognized the value of connecting science and technology since at least 1983, with the creation of Engineering Research Centers (Bozeman and Boardman, 2004), followed by Science and Technology Centers in 1987 and continuing in the past decade with the creation of the I-Corps program.

Meanwhile, in mission-oriented agencies such as DOE and the National Institutes of Health (NIH), the debate over public funding for applied research is more acute. Boundaries are often drawn to separate basic and applied research, perhaps due to the political tension surrounding transactions between government agencies and private firms. The appropriate balance between basic and applied research funding in the life sciences is a subject of frequent debate (Collins, 2012; Comroe and Dripps, 1976; Moses et al. 2005), although a recent study found no substantial difference in commercial patenting as a function of "basicness" for NIH grants (Li et al., 2017).

Many observers have recognized the particularly sharp boundary between basic and applied research at DOE (American Academy of Arts & Sciences, 2013; Anadón et al., 2016; The National Academies, 2007). Research expenditures in DOE are divided among the Office of Science and four technology offices such as the Office of Energy Efficiency and Renewable Energy (EERE). While the technology offices fund "applied research, development, demonstration and deployment activities" (U.S. Department of Energy, 2016), the Office of Science identifies strongly as a basic research agency. A report published in 2014 by Basic Energy Sciences within Office of Science depicts a clear boundary between basic research and all other department activities (Figure A1), even listing distinct goals and metrics.

In response to growing concern over the effectiveness of DOE's research funding, Secretaries of Energy Chu and Moniz oversaw several important changes to the department. In 2010, DOE established several Energy Innovation Hubs, which are "integrated research centers that combine basic and applied research with engineering to accelerate scientific discovery that addresses critical energy issues" (Anadón, 2012; U.S. Department of Energy, Hubs). Several cross-cutting initiatives were created to combine expertise across the department in areas such as grid modernization and the energy-water nexus. In 2014, the DOE leadership structure was reformed to allow a single administrator (the Under Secretary of Science and Energy) to head up the Office of Science as well as the technology offices (Malakoff, 2014), although this change has since been reversed under Secretary of Energy Perry.

2.2. The role of ARPA-E

Another major change at DOE was the creation of ARPA-E in 2009; this new agency was intended "to overcome the long-term and high-risk technological barriers in the development of energy technologies" (110th Congress, 2007). Inspired in part by DARPA, ARPA-E was designed to accelerate transformational advances in energy technology (The National Academies of Sciences Engineering and Medicine, 2007). Rather than being embedded within either Office of Science or any of the technology offices, the Director of ARPA-E has greater flexibility by reporting directly to the Secretary of Energy. Because it exists outside the conventional departmental structure (Fig. 1), research funded by ARPA-E is not implicitly defined as either basic or applied.

Public documentation of ARPA-E's purpose often describes the agency as distinct from either exclusively basic or applied research. ARPA-E's authorizing legislation charged the agency with "identifying and promoting revolutionary advances in *fundamental* and *applied* sciences" (emphasis added) (110th Congress 2007; 111th Congress 2011). In its first annual report, ARPA-E was described this way: "By bringing together experts from all walks of science, technology, and business, ARPA-E breaks down silos between disciplines. This cross-disciplinary inquiry is essential to bridge the gap between basic and applied research and development." More recently, DOE's 2017 budget request described ARPA-E as "complementing and expanding the impact of DOE's basic science and applied energy programs" (U.S. Department of Energy, 2016).

In terms of Technology Readiness Level (TRL), ARPA-E has defined

[2] In 2014, the federal budget for R&D at DOE was approximately $12 billion for Defense, Energy, and General Science (National Science Foundation, and National Center for Science and Engineering Statistics, 2015).