Why Do Governments Pay for Your Research?

The Political Economy of Science Funding Decisions

June 4, 2018

ABSTRACT

Science produces value when it informs decisions and improves quality of life. Some scientific findings become public goods in that one person's use of scientific findings does not exclude others from using them. Since the private sector underinvests in public goods, governments fund scientific research. But, government officials raise questions about how much, and what kinds, of science to fund. Issues like changing topical priorities, shifts in economic conditions, and ideological considerations motivate government officials' questions.

We develop a formal model of the interactions between governments and research entities to examine how changing beliefs about the value of scientific findings combine with political pressures to influence funding decisions. Our work clarifies the likelihood that types of research receive government support. Likewise, we show how changes in circumstances may alter the way researchers talk about their work, and even how changing circumstances may influence the lines of inquiry researchers pursue.

Introduction

Scientific research provides many benefits. It generates knowledge of the natural and social world. It leads to the creation of new industries and the revitalization of others. It helps individuals and communities manage many important challenges. Science also helps governments, and many public-serving non-governmental organizations, deliver essential services more effectively (see, e.g., National Academy of Sciences 2016). Scientific research improves quality of life for people throughout the world.

Science's ability to produce widespread public goods affects how scientific research is funded. Some benefits of research are considered *public goods* because the benefits are non-exclusive (all may freely use the benefits of science) and non-rival (one person's benefit from scientific finding does not diminish the benefit that may accrue to another). As with any public good, potential beneficiaries have incentives to let someone else pay for it (a.k.a., the "free rider" problem). Prominent economic theories predict that free rider dynamics will cause the private sector to supply fewer public goods than is socially optimal (see, e.g., Olson 1965). Around the world, governments respond to the expected under-provision of scientific public goods by supporting scientific activities that are likely to provide highly valuable public goods.

Today, government funding provides the lifeblood for many research endeavors. This funding is not an automatic entitlement. Instead, it is a product of political decisions on questions such as: "How much money should we allocate to research?" and "What kinds of research should we support?"

If you are reading this paper, you likely have a substantial interest in these decisions. You may be interested in knowing what types of research governments will and will not support. You may want to know how these choices change over time. You may care about these things because you are interested in the progress of science. Alternatively, your interest may be more materialistic.

You may work for – or want to work for -- institutions that receive government funding (e.g., nearly all research universities around the world). You may work on – or want to work on -- projects that receive government support (such as those funded by national or state science foundations). Whether you already have a research career or are working to build one, political decisions about research funding are likely to affect what opportunities you have now -- and what opportunities you will (or will not) have in the future.

In this paper, we offer a theoretical framework to explain why politicians pay (or do not pay) for certain kinds of research. We use this framework to clarify how government support for research like yours will change in the years to come. Our work entails developing formal models of relationships between government decision makers, research entities, and the public. The models focus on how changes in available information affect government decision makers' perceptions of, and willingness to support, various types of research.

Why focus on changes in available information?

Many government agencies and knowledge producing institutions were formed in decades or centuries in which little scientific information was available and available information was difficult to obtain or store. It is worth recalling that for most of history in most places in the world, people had access to very little information about most topics. Typical households had few books, magazines, or newspapers. People had access to few or no library books due to limited access and restrictive borrowing policies. Most people in most places for most of human history had access to few or no television or radio stations – and no Internet. Until recently, even when information could be found, it was often difficult to store or retrieve for later use (there were no photocopiers, hard drives, cloud computing, or pdfs). Long distance telephone calls were expensive and, in many places, impossible. It was often prohibitively costly to travel long distances to gather information that was not locally available. This was the situation in 1950, for example, when the United States Congress created the National Science Foundation (NSF).

Times have changed. Evolving communication technologies produced a massive increase in the amount of information available on a wide range of topics. These technologies fundamentally transformed peoples' views of what can be known, who can be trusted, and who should pay (or not pay) for information. When such changes occur, decision makers have a legitimate rationale for asking rigorous questions about what kinds of science governments should fund (see, e.g., Cantor and Smith 2013, Smith 2017, Suhay 2017; also see Patty and Penn 2014).

Today, prospective funders, individual researchers, and a variety of research entities are trying to determine how best to achieve their objectives in these changing circumstances. In what follows, we seek to clarify for you how changes in the content and quality of available information affect the funding opportunities that you can expect to have.

Our work proceeds as follows. In the next section, we offer a deeper rationale for studying the political economy of research funding. Next, we present our theoretical work and a series of findings. The findings explain why government supports certain types of research. They also explain how changes in available information and associated political dynamics have, and will continue to, affect the kinds of research governments want to fund. With these findings in hand, we close by offering conclusions about actions that scholars and scholarly institutions can take to improve the public value and funding potential of their work now and in the future.

Our analysis suggests at least two ways that researchers might increase their prospects of winning government support for their work in the coming years. First, as alternative sources of knowledge become easier and less costly to obtain, research entities that wish to secure government support must devote increasing resources towards clearly articulating the value of their research to government decision makers. Second, these same circumstances imply that a researcher's freedom to engage in her or his preferred type of research will become increasingly reliant on government decision makers' patience. If political circumstances lead decision makers to require more immediate or certain benefits from scientific research, researchers who want to engage in certain kinds of basic or long-term research will find fewer funding opportunities. At the end of this paper, we describe how researchers and research entities can adapt to both circumstances in ways that simultaneously create new research opportunities and tangible public value.

Motivation: Changing Perceptions, Funding Decisions, and Academic Freedom

In a *Washington Post* editorial, Eric Schmidt, the then Executive Chairman of Alphabet, Inc., the parent company of Google, and Eric S. Lander, the President of the Broad Institute of MIT and Harvard, penned an editorial about "America's miracle machine" (2017).

> "For more than a half century, the United States has operated what might be called a "Miracle Machine." Powered by federal investment in science and technology, the machine regularly churns out breathtaking advances.
>
> The Miracle Machine has transformed the way we live and work, strengthened national defense and revolutionized medicine. It has birthed entire industries — organized around computers, biotechnology, energy and communications — creating millions of jobs. It's the reason the United States is the global hub for the technologies of the future: self-driving cars, genome editing, artificial intelligence, cancer immunotherapy, quantum computers and more.
>
> Our machine is the envy of the world. And yet, while other nations, such as China, are working furiously to develop their own Miracle Machines, we've been neglecting ours…"

The op-ed goes to on lament proposals to significantly reduce government support for the National Science Foundation and National Institute of Health and related agencies.

Concern about the future of science funding is widespread. Leaders of education, business and industry have made impassioned arguments about science funding's broad private and public benefits. Individual scholars are also feeling the heat. Many state governments are pulling back on university funding by offering increases in funding below the rate of inflation or by reducing nominal budgets (Chronicle of Higher Education 2014).[1]

Others feel different pressures. Some elected representatives have questioned whether current peer review processes are effective ways to produce the best science for the nation (Mervis 2015, 2017). Others state strong preferences about the types of research that governments *should not* support (Smith 2017). In recent years, prominent members of the United States Congress have proposed the reduction or elimination of specific programs at the National Institutes of Health and the National Science Foundation.

In government, a decision to fund particular portfolios of scientific activity requires the political support of a sufficiently large legislative coalition. In elected legislatures, majorities are almost always needed. Supermajorities are sometimes also required (as is often the case in the United States Senate). As a consequence, government science funding decisions are inherently political – they require individuals and groups with potentially diverse interests to use persuasion and leverage to produce sufficiently large supportive legislative coalitions.

To obtain support for a science-funding proposal, decision makers must be able to explain -- to their constituents *and* peers -- why funding certain types of research produces value for each group (Lupia 2014). These explanations are a crucial component of democratic accountability. However, the need to offer these explanations produces a difficulty. Scientific inquiry is often hard to explain. It can involve great uncertainty and early-stage error. Scientists, moreover, often have little training in how to explain the value of their activities in ways that intelligent non-scientists can understand.

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[1] In a parallel development, younger scholars are experiencing a steady decline in the percentage of new PhDs obtaining tenure track jobs (American Institutes for Research 2014). This trend is due to several factors including growth in the number of doctorates conferred as well as growing numbers of colleges and universities moving away from hiring faculty to tenure-track positions and moving towards hiring more people in temporary positions such as post-docs, lecturers, or adjunct instructors.

To complicate matters further, funding agencies have limited resources to invest. To win funding, research entities must convince funders that their project is better than some alternative activity that could also receive support. In competitive funding environments, where many other social interests are appealing for greater support, supporters of a particular funding proposal need to persuade pivotal decision makers that proposed activities generate *significant and distinctive net benefits to key constituents*. If competitors can argue that other programs, or reduced taxes, also create social value, then science's prospective supporters must be willing and able to make arguments about the science's benefits *relative to other alternatives*.[2]

The idea of comparing science to other activities is anathema to many academics. About government, some members of the science-industrial complex say, "*They* should fund all science at much higher levels." This is an interesting suggestion, but how much higher should the funding be?

A challenge inherent in answering such questions is that the amount of resources available for any prospective science funder is far smaller than the full set of activities to which resources can be allocated. This is true because science can study numerous topics in an infinite number of ways. So, "everything" can't be funded. "Everything" is infinite. Funding is finite. So, tradeoffs of real options against real options must be made.

How do science supporters make these arguments? One approach, that some advocates use to try to stack the deck in favor of their desired activities, is to compare their favored activity to the consequences of "doing nothing." While such arguments may carry the day in sympathetic environments, they are less effective when skilled competition is present. For example, if a science advocate asks, "what would happen if we didn't conduct this study" the most correct answer from a competitor, or prospective funder, is that "we would not have your findings but would have the

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[2] The argument in the remainder of this section summarizes an argument made at greater length in Lupia (2017).

benefits of the alternate activities on which those funds were spent." Therefore, current and prospective social science funders have incentives to fund scientific activities that produce valuable material benefits *in comparison to other activities that the same funds could support*. For funders who face time pressure, such as looming elections or impatient governing boards, research that can produce iconic successes quickly will be in greater demand.

Again, some academics and science advocates scorn the idea that proposals to government science agencies or science funding decisions should be affected by such "politics." Some desire a clean split between science and politics. Of course, if politics interferes with proper implementation of the scientific method (with respect to design specifications, analytic techniques, and adherence to norms of transparency) so much that resulting claims cannot truly be called "scientific", then that political interference undermines science's critical value-proposition – that its findings are broadly credible because they are as independent as possible from the ideological, metaphysical, or cultural commitments of the person who conducted or funded the research.

Still, government is needed. The private sector cannot be counted on to supply scientific public goods in socially optimal amounts. As a result, a society that wants to improve effectiveness and create efficiency needs government to fund the public goods that only science can create. And when government funding appears, so does politics. *There is no way around this*.

Hence, for individuals, small research groups, middle-sized labs and very large knowledge-producing entities, decisions about what to study – and how to study a topic – cannot be independent of political dynamics if government funding is desired. When science organizations give more grant money to some topics rather than others, and when universities increase the size of some academic programs and not others, they do so as part of broader academic ecosystems with channels of political accountability and associated financial incentives. Scholars who do not need resources for their research, have greater freedom to study what they want and how they want to. For others, research opportunities and academic freedoms at any given moment are not indefinite entitlements; they are products of ongoing negotiations. We now examine how changes in the amount and content of available information affects key aspects of these negotiations and seek to clarify the consequences for government, researchers, and the public.

Two Models of the Political Economy of Research Funding

In this section, we introduce two models of science funding decisions. We use the models to examine how changes in the kinds of available information affect the types of research governments will want to support and the kinds of adaptations that research entities will be incentivized to make if they want their work to be funded.

The interactions represented are between a government agency and a research entity (which could be a single researcher or a larger research organization), and the public. Everyone is potentially influenced by an *exogenous factor*. This exogenous factor represents information available to the public and government agency from sources other than the research entity.

The agency's and public's choices in the models are whether or not to support the research entity. If they support the research, then the research influences their future well-being. If they refuse to support the research, then they do not receive its benefits. The agency and public may begin the interaction with different views about whether or not supporting research makes them better off. The research entity, in turn, desires government support as well as *personal rewards* of conducting research (e.g., salaries, benefits, access to office space and research infrastructure, reputation, prestige, the thought of helping others, the joy associated with inquiry and discovery).

We present our work in the form of two models because it allows us to simplify the presentation of two different ways that research entities can be simultaneously supported and constrained by interactions with government funders.

- In "Model 1," we examine how changes in public and agency beliefs about the exogenous factor affect how researchers talk about their science. In this model, the research entity's dilemma is whether to direct resources away from research and towards communication.[3]
- In "Model 2," we examine how political and exogenous factor changes affect government decisions about what kinds of research to support. In this model, the research entity's dilemma is whether to change what thy doing in an attempt to earn greater support.

In both models, it is possible that highly beneficial research will not be supported. Because this type of outcome can lead to very bad outcomes for everyone involved, we focus special attention on it when interpreting our findings. We now describe each model and present key findings. We conclude this section by describing broader implications of this work.

MODEL 1

Basic Elements. This section describes a model of an interaction between a research entity, a government funding agency, and the public. The agency and public may not initially know the value of research relative to the exogenous factor. The research entity may subsequently provide them with more information about this fact. The agency and public can use or ignore the information. They then decide whether or not they want to support the research. If they do not support their research, the exogenous factor, and not the research, determines their subsequent well-being. The main themes of findings related to Model 1 are:

- As the agency or public comes to believe that the exogenous factor can help them make better decisions, their support of science requires the research entity to put greater effort into effectively communicating public benefits of research.

[3] See Ellison 2002 for an inquiry into decisions about whether to move content-effort into communication-effort and Gailmard and Patty 2014 for a review of inquiries into analogous dynamics within and across government agencies.

- In some cases, high-quality research is not supported. This happens when the research entity lacks sufficient skill or motivation to communicate more effectively and/or the agency lacks sufficient motivation to support research whose substantial benefits are not widely appreciated.

Players. The game has three players, the research entity *R*, the government agency *G*, and the public *P*. All are interested in maximizing their well-being. The public derives well-being from its ability to solve a problem. Research findings may help the public do this. Likewise, the agency derives utility from its ability to solve a problem and research may help them. The agency receives additional utility from supporting research the public likes. The research entity obtains utility from a number of factors including government support.

Sequence of Play. The sequence of events in the game is as follows:

- Nature chooses whether the research in question is of a high-type or a low-type. We denote this outcome as $T \in \{t_H, t_L\}$.
  - t_H represents research that is better than an exogenous factor, r, in helping the government and public obtain higher utility.
  - t_L represents research that may not have this quality

Given our focus on the political funding decisions, "type" in this model refers to a correspondence between research content and the other actors' subsequent well being.

- The research entity observes its type, *T*, and then sends signal $M|T \in \{0,1\}$.
  - $M|T=1$ is a signal that the research can improve public and agency utilities. This message can be thought of as a research entity's attempt to make its findings' more

relevant and accessible to other players -- or as work needed to convert research findings into forms that other players can apply.

  - Sending this message costs $c_H>0$ or $c_L>0$, depending on the research entity's type. We assume that $c_L > c_H$, reflecting the idea that it is marginally easier for high-type research entities to cultivate others' support.
  - Sending message $M|T=0$ entails no cost.

- The public observes the research entity's message M and then chooses $X_p|M\in \{0, 1\}$.
  - $X_p=1$ represents the public supporting the technology and having it affect their subsequent well being.
  - $X_p=0$ represents using the exogenous factor as the basis of its subsequent utility.
- The government agency observes the research entity's message M and is aware of public support, X_p. It then chooses $X_g|M, X_p\in \{0, 1\}$.
  - $X_g=1$ represents supporting the research and using it as the basis of its subsequent ability.
  - $X_g=0$ represents rejecting the research and relying on the exogenous factor as its knowledge base.
- Outcomes are realized and the game ends.

Utilities. The research entity's utility depends on several factors. The factor $b>0$ reflects personal benefits of research that is independent of the value it derives from agency funding (e.g., the joy of discovery, professional reputation, imagined public benefits). The factor $v>0$ measures how much the research entity values external support relative to personal benefits. Higher v implies greater interest in others' support. As stated above, we assume that the research entity can send a costly signal about the value of its work, and that the cost of this signal depends on its type.[4]

Research entity payoff:

- If $M=1$, then $b + v^*(X_g | 1, X_p) - c_i,\ i \in \{H, L\}$.
- If M=0, then $b + v^*(X_g | 0, X_p)$

The public's utility function comes from its ability to accomplish a task (which represents a portfolio of tasks for which the research in question may be useful).

Public payoff:

- U_{p+} if $X_p=1$
- U_{p-} if $X_p=0$
- $U_{p+} \in \{t_H, t_L\},\ U_{p-}=r$

The agency's utility is a function of its ability to accomplish a technical task and the extent to which its support of research or the exogenous factor is consistent with the choice that the public makes. We presume that $s>0$ which reflects the value that the agency receives from making the same choice as does the public.

Government agency's payoff

- $U_{g+} + s$ if $X_g=1$ and $X_p=1$
- $U_{g-} + s$ if $X_g=0$ and $X_p=0$
- U_{g+} if $X_g=1$ and $X_p=0$
- U_{g-} if $X_g=0$ and $X_p=1$
- $U_{g+} \in \{t_H, t_L\},\ U_{g-}=r$

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[4] To simplify the presentation, we assume that $c_L < b$. This implies that playing the game (if we were to give the researcher a choice) is always incentive compatible, but paying to send a quality signal need not be.

By assumption, $t_H > U_g$, $t_H > U_p$, and $t_H > t_L$. That is, high type research has greater value to the public and the government agency than does low type research or the exogenous factor.

An implication of these definitions is that public support affects the research entity's utility only indirectly. In other words, the public's choice (X_g) appears in the agency's utility function but not in the researcher's utility function. That said, there are two ways that the public can influence researcher incentives in this model. First, public support is explicitly included in the agency's utility function. So, if the agency places sufficient value on public support (s sufficiently high) and if the research entity places sufficient value on agency support (v sufficiently high) then the research entity's beliefs about public welfare can influence its own strategies and utility. Second, a research entity's public concern can also manifest as higher values of b. In other words, they may obtain psychic benefits from conducting research because they imagine that it will benefit the public.

Beliefs. We assume that the public has prior ($q_p \in [0,1]$) and posterior ($w_p \in [0,1]$) beliefs about the probability that $T = t_H$. These beliefs are common knowledge, but they need not be correct.

We assume that the agency has prior ($q_g \in [0,1]$) and posterior ($w_g \in [0,1]$) beliefs about the probability that $T = t_H$. These priors need not be identical to those of the public and they need not be correct. We assume that the research entity and the agency know the agency's priors, but that the public knows only its own priors. We use these assumptions believing that they offer an accurate representation of the situation in which prospective funders often find themselves.

We represent the extensive form of this game as Figure 1.

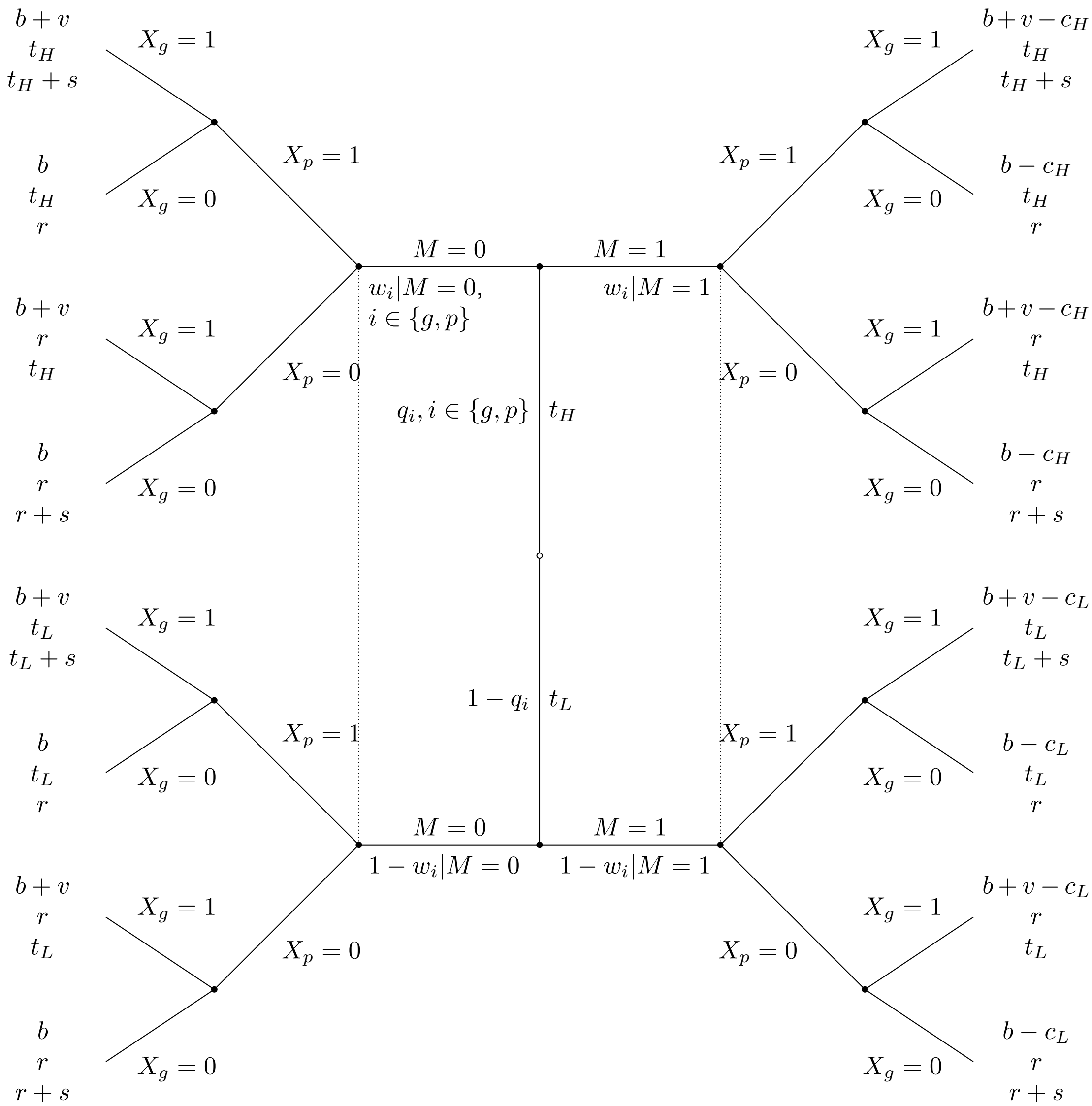

FIGURE 1: A depiction of Model 1. Nature determines research type. The research entity chooses whether or not to make its work more accessible. Then, the public and government decide whether or not to support the research.

Analysis. This game produces several substantive findings. We produce these findings through the discovery of three different phenomena. First, there exist *Ivory Tower Equilibria*, a class of perfect Bayesian equilibria where the public and agency's prior beliefs about research benefits are so positive that they are simply imagined to exceed the benefits of basing future decisions on the exogenous factor. In this case, the public and agency support the research, and the research entity does not need to devote any effort to self-promotion. Many academics regard this situation as what should be in place all of the time. As our subsequent analysis reveals, this outcome cannot survive familiar types of changes in what the public or government decision makers believe about the exogenous factor.

A *Skeptical Consumer Equilibrium* also exists. This is a separating equilibrium where the research entity promotes its work only when its research quality is high. Here, the agency or public initially believe that the research will not help them relative to the exogenous factor. If the research entity is sufficiently motivated to serve the public or obtain support (i.e., if *v* is sufficiently high), then it will make the effort to alert others of its quality in the conditions where this equilibrium exist. Initially skeptical actors, in turn, will learn from the signal that the research merits support.

After presenting these two equilibria in greater detail, we describe a third set of conditions under which agency chooses not to support high-type research. In short, when the government places sufficiently high value on supporting the same technology as the public, it will sometimes choose not to support research that benefits the public.

Ivory Tower Equilibria

The research entity opts for the less costly signal, *M=0*, if the value of both t_H and t_L exceeds the value of the exogenous factor for the agency and the public and the research entity believes that the public and agency have beliefs that will lead them to support research in the absence of a quality signal.

PROPOSITION 1.1 *If* $t_H > t_L > r$*, then the research entity will always opt to send the less costly signal.*

The intuition for Proposition 1 is straightforward. If the public and government perceives that the value of research exceeds anything that is available from an exogenous factor, then they will support the research regardless of whether or not the research entity sends a signal. In other words, when the alternative information sources do not provide valuable solutions to the problems faced by the agency and public, the research entity has fewer incentives to make its work more accessible. One might characterize this as a situation more common prior to the Internet, when alternative sources of information on many topics were quite scarce.

Skeptical Consumer Equilibrium

PROPOSITION 1.2 *The research entity sends* $M|H=1$ *and* $M|L=0$ *iff* $c_L > v \geq c_H$ and $r > t_L$

Proof:

To simplify the explanation, we label each of the relevant information sets. Let Pm and P- denote information sets where the public observes $M=1$ and $M=0$ respectively. Let Gmp denote the information set following $M=1$ and $X_p=1$, let Gm- denote the information set following $M=1$ and $X_p=0$, let Gp denote the information set following $M=0$ and $X_p=1$, and let G- denote the information set following $M=0$ and $X_p=0$.

For $M|H = 1$ and $M|L = 0$, it must be the case that

(1) $c_L/v > (X_g|(1, X_p|1))-(X_g|(0, X_p|0)) \geq c_H/v$.

If $M|H = 1$ and $M|L = 0$, then by Bayes' Rule $w_G=w_P=1$ at information sets following $M=1$. Then, at information set Pm it must be the case that $U_{p+}=t_H$. Since, $t_H>U_{p-}$ by assumption, $X_p|1=1$. By similar logic, and since $s > 0$, $X_g|(1, X_p|1)=1$, at information sets Gmp and Gm-.

Hence, requirement (1) becomes

(1') $c_L/v > 1 -(X_g|(0, X_p|0)) \geq c_H/v$

If $M|H = 1$ and $M|L = 0$, then by Bayes' Rule $w_G=w_P=0$ at information sets following $M=0$.

So, at *information set P-*

$X_p|0 = 1$ if $t_L \geq r$

$X_p|0 = 0$ if $t_L < r$

At information set Gp

$X_g|0,1 = 1$ if $t_L \geq r - s$

$X_g|0,1 = 0$ if $t_L < r - s$

At information set G-

$X_g|0,0 = 1$ if $t_L \geq r + s$

$X_g|0,0 = 0$ if $t_L < r + s$

Therefore, $M|H = 1$ and $M|L = 0$ elicits $Xp|0=1, Xg|0,1=1$ when

$q_P*t_H + (1\text{-}q_P)*t_L \geq r$
$q_G*t_H + (1\text{-}q_G)*t_L \geq r - s$

Since $q_G=q_P=0$ in this case, the requirement simplifies to

$t_L \geq r$
$t_L \geq r - s$

which, since $s>0$ simplifies to $t_L \geq r$

(2) So, $M|H = 1$ and $M|L = 0$ elicits $X_p|0=1, X_g|0,1=1$, when $t_L \geq r$.

By similar logic,

(3) So, $M|H = 1$ and $M|L = 0$ elicits $X_p|0=1, X_g|0,1=0$, when $r - s > t_L \geq r$
(4) So, $M|H = 1$ and $M|L = 0$ elicits $X_p|0=0, X_g|0,0=1$, when $r > t_L \geq r + s$
(5) So, $M|H = 1$ and $M|L = 0$ elicits $X_p|0=0, X_g|0,0=0$, when $r > t_L$

Given consistent beliefs at these information sets, the stated strategies for $X_p|0$ *and* $X_g|0, (X_p|X_g,0)$ and $M|H = 1$ and $M|L = 0$ are mutual best responses if

(1' & 2) $c_L > v \geq c_H$ & $t_L \geq r$

- However, since $c_H>0$ and $v>0$, $0 \geq c_H/v$ is impossible.
- Hence, the research entity will not condition its signal on its type when agency and public priors about the exogenous factor are sufficiently negative. The agency and public will support the research without the signal.

(1' & 3) It must be that $c_L > 0 \geq c_H$ and $r > t_L + s \geq r + s$
(1' & 4) It must be that $c_L > v \geq c_H$ and $r > t_L \geq r + s$

- Since $s>0, r > r + S$ impossible. In other words, along the path, the agency and public cannot have posterior beliefs that lead to different conclusions about the relative value of r and t_L.

(1' & 5) It must be that $c_L > v \geq c_H$ and $r > t_L$

- Here, the prior is that the exogenous factor is better than low type research, the cost of the low type sending the signal is high relative to v and c_H. As other-regardingness increases, the high type research entity is more likely to signal.

Therefore, $M|H = 1$ and $M|L = 0$ iff $c_L > v \geq c_H$ and $r > t_L$ ***QED.***

We make one observation about this equilibrium. First, the researcher must care about agency support (v) relative to personal research benefits for the situation to induce them to sacrifice time at the bench in order to convince others of their work's value. If v is sufficiently low, the research entity will forgo opportunities to improve their communicative effectiveness.

Implication: When Does the Government Choose Not to Support High-Type Research?

A common concern in many conversations about government funding decisions is that it may not choose to fund high quality research. In other words, "If $T=t_H$, does $X_g=0$?" Proposition 3 describes the conditions under which this outcome occurs.

Proposition 1.3. The agency rejects high quality research when one of the following situations applies:

a) $s < r - w_G{*}t_H - (1w_G){*}t_L$ *and* $w_P{*}t_H + (1\text{-}w_P){*}t_L \geq r$

b) $w_G{*}t_H + (1\text{-}w_G){*}t_L - r < s$ *and* $w_P{*}t_H + (1\text{-}w_P){*}t_L < r$

Proof:

Since, $c_L > c_H$, there is no Perfect Bayesian Equilibrum where a low type research entity sends $M=1$, when the high type does not. This leaves three possible pure strategy profiles for the research entity $(M|H=M|L=0)$, $(M|H=M|L=1)$, and $(M|H=1, M|L=0)$.

First, consider the case, $M|H=1, M|L=0$ as an element of a PBE. Then, the agency can be at two information sets Gmp and Gm-.

At Gmp, $X_g|1,1 = 0$ if $w_G{*}t_H + (1\text{-}w_G){*}t_L < r - s$. Given a separating signal, the requirement becomes $t_H < r - s$. Since, $t_H > r$ by definition, the agency will not reject high type research in this case.

At Gm-, $X_g|1,0 = 0$ if $w_G{*}t_H + (1\text{-}w_G){*}t_L < r + s$. Given a separating signal, the requirement becomes $t_H < r + S$. In this case, the agency will reject high quality research if $t_H - r < S$. To reach this information set, however, it must be the case that $w_P{*}t_H + (1\text{-}w_P){*}t_L < r$. Given a separating signal, the requirement becomes $t_H < r$, which is impossible.

Therefore, the agency will not reject high type research when $M|H=1, M|L=0$.

Now, consider $M|H=M|L$ as an element of a PBE. In a pooling equilibrium, posterior beliefs along the path must be $w_G=q_G$ and $w_P=q_P$. To simplify the proof, we assume that off-path beliefs are the players' respective priors.

To reach information set Gmp or Gp, it must be the case that $X_p=1$, which implies $w_P{*}t_H + (1\text{-}w_P){*}t_L \geq r$. Therefore, the requirement becomes $s < r - w_G{*}t_H - (1w_G){*}t_L$ and $w_P{*}t_H + (1\text{-}w_P){*}t_L \geq r$.

At Gm and G-, by similar logic, the requirement becomes $w_G{*}t_H + (1\text{-}w_G){*}t_L - r < s$ and $w_P{*}t_H + (1\text{-}w_P){*}t_L < r$. Hence if r is sufficiently small relative to w_P and if s is sufficiently large relative to w_G and t_H, the agency will reject high type research to gain public support. ***QED.***

In situation (a), the **government rejects high type research eventhough the public has adopted it**. This situation occurs when:

- the agency's prior beliefs lead it to incorrectly assess research as not valuable relative to other available information, and
- a high-type research entity lacks sufficient incentive, or faces sufficiently high costs, to send a quality signal that differentiates it from low-type research entities.

Here, the research entity can lack an incentive to make its value more accessible because c_H is high (they find it very costly to communicate effectively; perhaps due to lack of skill) or because v is low (they perceive themselves to have little or no personal stake in public or governmental approval of their research). This situation is tragic when lower communication costs for high-type researchers, or high-type researchers being more concerned about perceived public value of their research, would have been sufficient for them to put effort into communications that would help the agency make a better decision.

Where situation (a) is tragic, situation (b) is more of a "nightmare scenario" for science advocates. In this case, the high-type research entity lacks sufficient motivation to communicate effectively. **Here, the government rejects high type research even though it believes that the research is better for the public than the exogenous factor.** It does so because the utility bonus the agency receives for following public opinion induces the agency to sacrifice quality of life benefits in return for public adoration.

Attributes of conditions (a) and (b) offer indications about how these negative consequences can be avoided or mitigated. Constructive changes include:

- attempting to educate the public – and, hence, changing its behaviors in ways that the politicians in this case will want to emulate
- attempting to educate government – so that it changes how much decision makers weigh accomplishing policy goals vis-à-vis gaining short term public support
- lowering the cost to high-type researchers of sending a quality signal. This could be done by including more effective communication training as part of graduate-level science education.

Note that more effective communication is not tantamount to simplification for its own sake. Instead, it is about learning how to more effectively convey complex ideas. These deliverables, along with iconic reminders of concrete research benefits, can help legislators, research institutions, and individual researchers more effectively build broader and more stable support for socially valuable public good research.

MODEL 2

In Model 1, we focused on whether exogenous factor changes induce research entities to devote greater resources to conveying the value of its work. Another possible consequence of exogenous factor changes is changes in the types of research that governments want to fund. Model 2 focuses on this relationship.

In this model, the research entity makes a different decision. It proposes to the agency a portfolio (a mixture) of "basic" and "applied" research. In this model, we use these terms to reflect different types of work that researchers can do. Applied research provides relatively certain and specific benefits in the near term. Basic research's benefits are less certain and immediate. In mathematical terms, applied research produces relatively certain benefits. Basic research's benefits are relatively uncertain and accrue in the future.

We acknowledge that the basic-applied distinction between varies by academic field -- and often varies within fields. Since these terms can be controversial, we offer an analogy to clarify our usage. In the 1970s, people depended heavily on vinyl records to store and reproduce certain types of information, such as recorded music. Vinyl records are undeniably useful. However, a single vinyl record can hold only about 44 minutes of recorded sound.[5]

Research entities in the 1970s had the ability to conduct applied research on how to incrementally increase vinyl record capacity. They also had the ability to conduct more basic research on digital encoding and compression of sound (see. e.g., Brandenberg and Stoll 1994). The benefits of that research would not have been immediately apparent to most people at the time.

This basic research was in fact conducted in places like Germany and the United States. In the decades that followed, the work led to many valuable applications. For example, basic research into encoding and compression (e.g., Schroeder et al 1979) helped to produce the 160 gigabyte iPhone. This device holds the equivalent of more than 3600 vinyl records. Related applications of this basic research allows medical records and other critical social information to be sent to people in need quickly and inexpensively. Today, benefits of that era's basic research are recognized as transformative even though they would have been hard to explain at the time. Table 1 shows other examples of basic and applied research that reflect our usage.

[5] Presuming the record is two-sided, 12 inches in diameter, and cut at 33rpm.

	Definitions:	
	Applied research provides an immediate, practical solution to a particular problem in which the solution depends on some understanding of the fundamental aspects of the physical or social world.	**Basic research** provides additional understanding of fundamental aspects and phenomena but may that lack an immediate use in solving a specific problem.
	Some examples of questions addressed by applied or basic scientific research:	
Physics	How do you bring an object in orbit safely back to the earth's surface?	What are the origins of the universe?
Chemistry	How do you manufacture small, portable, rechargeable batteries?	What are the electro-chemical properties of lithium?
Biology	What is a strain of wheat that may be cultivated in diverse climates?	What are the molecular-genetics of different varieties of wheat?
Economics	How can you get more people to take the bus to work rather than drive a car?	What are the mathematical properties of a particular solution concept in game theory?
Sociology	Why did a social program fail to help its intended population?	How and why to group identities form?
Political Science	What is the most effective form of campaign communication?	How do individuals gain or lose the trust of another individual?

Table 1: Definitions of basic and applied research along with a set of examples of basic and applied research from various scientific fields.

In Model 2, the research entity seeks government support by proposing portfolios that mix basic and applied research. The government agency accepts or rejects the proposed portfolio. The agency's utility depends on the portfolio's true value if they support it or on the exogenous factor if they reject it. A critical component of the agency's utility function is how much the agency prefers immediate benefits relative to long-term benefits.

We use Model 2 to show how changes in the value of the exogenous factor, and in a government agency's willingness to wait for benefits, affect the types of portfolios that are funded, and the ways in which research entities may have to change their research to obtain support. The main themes of our findings are as follows:

- As government need for immediate outcomes, or belief in the value of the exogenous factor, increases, basic research support declines.
- When this happens, research entities that desire public support can become significantly constrained in the types of portfolios that they can pursue.

Basic Elements, Players, and Sequence of Play. This game has two players, a research entity, *R*, and a government agency, *G*, and two periods. The game begins when the research entity proposes a research portfolio, $x_1 \in [0,1]$. Here, x_1 represents the amount of "basic" research in the portfolio and $1 - x_1$ represents the amount of applied research. The agency responds by accepting or rejecting the proposal. If the agency rejects the proposal, the game ends. Otherwise, it continues.

The second period in this model represents a future that the government and research entity may consider when making their initial decisions. In period 2, the research entity proposes a second research portfolio, $x_2 \in [0,1]$. The game ends after government accepts or rejects the second offer.

Our analysis focuses on how the government's beliefs about the future and its preferences for earning utility at different points in time influence its willingness to support basic research in period 1.

Utilities. Let r be the research product produced by the exogenous factor. Likewise, let t_l^a and t_l^b be the applied and basic research produced by the research entity in period l. If the agency rejects x_1, then the game ends and the exogenous factor is the basis for both players' subsequent payoffs. If the agency accepts x_1 and x_2, then it receives a payoff derived from the applied research produced in period 1 plus a second period payoff that combines returns from basic research supported in period 1 and any applied research that it supports in period 2. We write this payoff as the linear combination of the benefits provided by R's basic and applied research in either period as embodied in its proposal x_l,

$$(1 - x_1)t_1^a + x_1\delta(x_2 t_2^b + (1 - x_2)t_2^a),$$

where $\delta \in [0,1]$ is the degree to which the agency discounts the utility it receives in the second period. For example, when $\delta = 1$, the agency values the future as much as it values the present, and when $\delta = 0$, it does not value the future at all. If the agency rejects x_2 (that is, if it ends funding for basic research before the game ends), then it receives a payoff derived from the applied research supported in period 1 and the exogenous factor,

$$(1 - x_1)t_1^a + x_1\delta r.$$

The research entity's payoff depends on the kinds of research it is permitted to do. Let $b(x_1, x_2)$, a linear function that combines the benefits of basic and applied research for the research entity in period 1 and period 2,

$$b(x_1, x_2) = (1 - x_1)A + x_1(B + x_2 B + (1 - x_2)A).$$

Analysis. Like the first model, the game we describe in this section has an *Ivory Tower Equilibrium.* The equilibrium arises when the value of any kind of work done by the research entity exceeds the value of that the government receives from the exogenous factor. Under these conditions, the research entity is free to choose the kind of work it does according to its preference for basic or applied research. This is situation reflects periods where alternative sources of information would be difficult for government to access.

PROPOSITION 2.1 (Ivory Tower): *If* $t_l^\alpha > r \; \forall \; t_l^\alpha \; \alpha \in \{a, b\}$*, then the research entity will set* x_l *according to its preference for basic or applied research.*

Now consider an alternative setting. Here, the agency obtains greater period 1 utility from the exogenous factor and applied research than it does from the current value of period 2 benefits of basic research. These preferences could reflect low prospects for basic research producing an outcome of real value or it could reflect severe time discounting – in other words, an agency that for political reasons needs results that it can apply right away (e.g., before a consequential budget vote or election). This scenario produces a second set of cases – the *Constrained Academic Freedom equilibrium.*

PROPOSITION 2.2 (Constrained Academic Freedom): *If* $t_i^a > r > t_2^b$ *, then* $x_1^* < \frac{t_1^a - r}{t_1^a - \delta r}$.

Proof:

Suppose $A \geq B$. In period 2, R accepts any offer $x_2 \in [0, 1]$ such that

$$x_2 t_2^b + (1 - x_2) t_2^a > r.$$

By setting $x_2 = 0$, R maximizes $x_2 B + (1 - x_2) B$ and satisfies the above inequality. Thus, the equilibrium in the subgame is for R to offer $x_2^* = 0$, and for G to accept in period 2.

In period 1, R accepts $x_1 \in [0,1]$ where

$$(1 - x_1) t_1^a + x_1 \delta (x_2^* t_2^a + (1 - x_2^*) t_2^a) > r.$$

An allocation of resources $x_1 = 0$ maximizes $(1 - x_1)A + x_1(B + x_2^* B + (1 - x_2^*)A)$ and satisfies the above inequality. Thus, R offers $x_1^* = 0$ and G accepts in period 1 when $A \geq B$.

Suppose $A < B$. In period 2, G will reject any $x_2 > \frac{t_2^a - r}{t_2^a - t_2^b}$; however, R maximizes $x_2 B + (1 - x_2) A$ with $x_2^* = 1$. Since $x_2^* > \frac{t_2^a - r}{t_2^a - t_2^b}$, G rejects x_2^* in period 2.

In period 1, G only accepts $x_1 \in [0,1]$ where

$$(1 - x_1) t_1^a + x_1 \delta r > r.$$

Only $x_1 < \frac{t_1^a - r}{t_1^a - \delta r}$ satisfies the above inequality, so R offers $x_1^* < \frac{t_1^a - r}{t_1^a - \delta r}$. ***QED.***

The contrast between the ivory tower result in Proposition 2.1 and the constrained academic freedom result in Proposition 2.2 is instructive. From Proposition 2.2, we understand that even if a research entity has a strong preference for basic research, it must engage in some applied research to "keep the lights on."

The need for shifting work to applied research (or more generally to work products whose broader impacts are more apparent and immediately applicable) increases as does the government agency's beliefs about future values of the exogenous factor (*r*) increase -- or as their need for immediate benefits (1- δ) increases. **As the agency comes to believe that the exogenous factor will provide sufficient future utility, its ability to commit to basic research funding diminishes**. Similarly, if the government is in a situation where it discounts the future heavily (perhaps due to a looming election or external threat) agency patience for research that can take a long time to deliver benefits will be in increasingly short supply.

Figure 2 depicts these dynamics. It shows the maximum amount of basic research that will be funded under different agency beliefs about the exogenous factor (increasing values of *r*) and, moving from left to right in the figure, decreasing agency patience for research that does not offer immediate payoffs.

[Figure 2 here]

Figure 2 shows that as the agency's beliefs about the value of the exogenous factor increases, or as it places less value on future benefits, its tolerance for basic research declines. In some cases the drop is quite precipitous.

Recalling the historical circumstances present at NSF's origin, we can infer that government officials are likely to have greater confidence in the exogenous factor than would have been the case in earlier decades. As a result, the dynamics demonstrated in Figure 2 are consistent with:

- NSF's increasing emphasis on documenting its impact,
- NSF's efforts to distribute that information in ways that are easier for government agencies and representatives to appreciate,
- NSF's increasing attention to "broader impacts" and
- the growing role that the broader impacts criterion play at NSF and similarly situated agencies throughout the world.

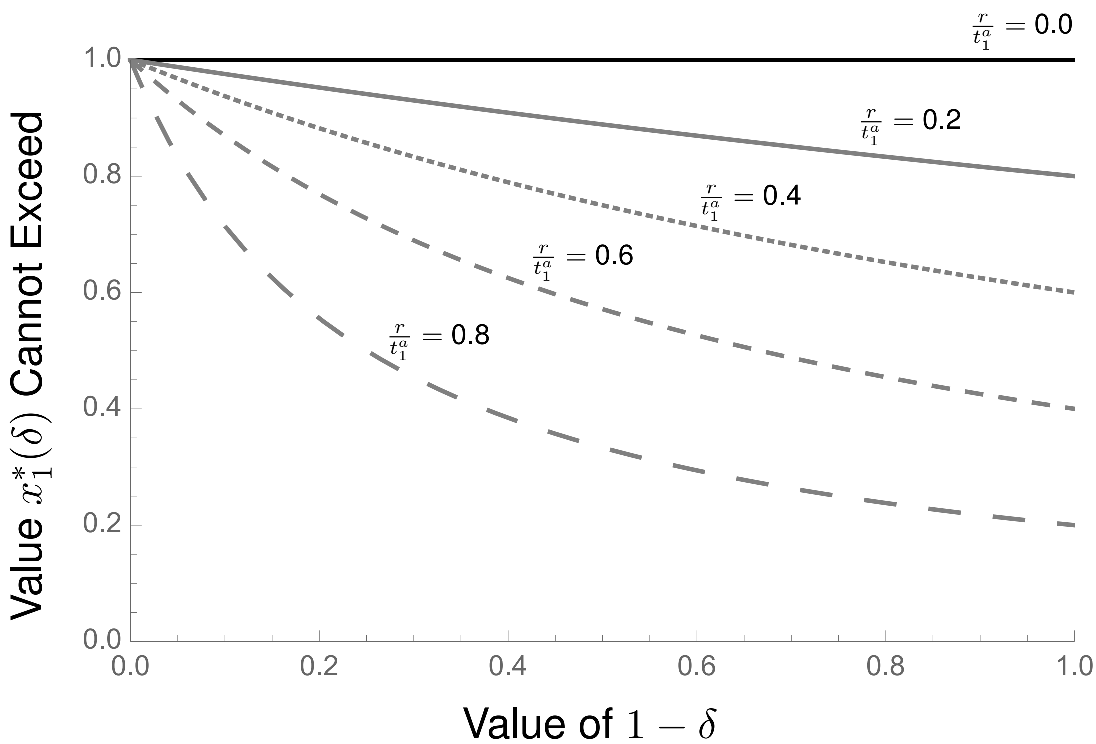

FIGURE 2: The relationship between δ and the value x_1^* may not exceed for various values of r and t_1^a. Conditional on the value of r relative to t_1^a, x_1^* must take larger or smaller values in order to satisfy G. When r and t_1^a are relatively similar, $\frac{r}{t_1^a} = 0.8$ for example, then x_1^* takes a smaller value than when r and t_1^a are relatively different, $\frac{r}{t_1^a} = 0.2$.

These results are also consistent with the emergence of a “moral hazard” problem for the research entities. In circumstances where funders require promises of more certain and more immediate benefits as a condition of funding, researchers may have incentives to promise them – and then revert to more basic work after funding is secured. This problem is particularly likely for researchers whose academic ecosystems offer greater rewards basic research advances.

Having introduced this moral hazard problem, it is important to point out that agencies are not powerless against them. They can reduce or eliminate such hazards through accountability mechanisms. Model 2 implies that such mechanisms should be more common and more rigorous as perceived value of the exogenous factor increases. Our experiences with federal agencies are consistent with this expectation. In particular, requiring detailed annual reports of research activity, and making future funding contingent on rigorous records of prior accomplishments, were once rare among federal science agencies but are now increasingly commonplace (see, e.g., National Science Foundation 2010).

More generally, our findings from Model 2 have important implications for research entities that desire government funding. In research fields where agencies are under greater pressure to produce immediate results, or in fields where funders are increasingly likely to believe that the “private sector”, “the Internet” or perhaps publicly funded research from other countries are likely to provide public good basic research, research entities will find increasingly fewer opportunities to get funding for work whose public benefits are uncertain, badly articulated, or distant in time. In these fields, there will be increasing pressure to do work whose immediate value is more apparent.

By contrast, in fields where funders are likely to believe that public good basic research will not be done by others -- or will be done and not shared (perhaps because it will be hoarded by private firms or it will be secured by countries seeking competitive advantages) -- research entities are likely to find greater willingness to fund more basic research. The US government's Minerva Research Initiative is a manifestation of such dynamics (http://minerva.defense.gov/). National security and defense are domains in which (a) other countries are less likely to share what they learn and (b) free-rider incentives reduce the likelihood that the private sector will produce the type of basic understandings that can aid its various military and security-related divisions. Hence, these agencies (that often have longer-term objectives and more stable funding prospects than other government programs) have created new opportunities for entities that are willing and able to produce basic research in these domains. Indeed, the Minerva Initiative is a conscious attempt to shift government-funded research portfolios in these domains in a more basic direction.[6]

A related implication is that when agencies' preferences about "benefits now" versus "benefits later" are different than the consequences of those preferences for the public, or when the government has overly optimistic beliefs about the exogenous factor (that is, what type of technical or customer service advantages can be produced without new investments in basic research) then even highly beneficial basic public good science will be underprovided. Hence, the dynamics discussed above have implications for the sustainability of "miracle machines." Consider, for example, the question, "What kind of countries can have a miracle machine – *and is ours still one of them*?"

Model 2 shows the importance of a scientific establishment that is responsive to a government's core needs. A government's willingness to fund research that does not have an immediate payoff depends on its confidence that what research entities can produce in the future justifies sacrifices made now. If research entities see themselves as independent of, or smarter than

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[6] The program's stated objective is as follows: "The Minerva Research Initiative, administered jointly by the Office of Basic Research and the Office of Policy at the U.S. Department of Defense, supports social science research aimed at improving our basic understanding of security, broadly defined. Supported projects are university-based and unclassified, with the intention that all work be shared widely to support the thriving of stable and safe communities."

government, when choosing the types of research topics to propose and pursue, and if those choices lead to activities that have no clear relation to society's most important needs, then the entities should expect that government confidence in their work will wane over time. Research entity responsiveness is particularly important when working with governmental agencies that are under extreme political or economic pressure. As our findings suggest, at these moments, potential legislative advocates will have a particularly difficult time convincing others to support research that is not directly relevant to needs that they see as urgent.

Consider, moreover, cases where legislative control is likely to switch from one set of parties to another prior to the time in which basic research is likely to produce its largest benefits. Our work suggests that research entities are most likely to secure basic research funding if their proposed portfolios lie at the intersections of those parties' core interests. If, instead, a research entity chooses the pet projects of a particular side, they risk getting cut off before their work can provide maximum social benefit. In this case, research entities that made such decisions would be complicit in creating circumstances where basic research support is imperiled.

For as long as science has the potential to produce public goods, and for as long as government support is required to supply socially optimal amounts of such goods, research entities that want to be constructive parts of vibrant and transformative "miracle machines" can achieve that purpose by keeping one eye on the best available scientific methods and the other on the types of problems that are of the highest value to the governments that fund them. In publicly funded systems, the range and content of fiscally sustainable academic freedom is endogenous.

Conclusion

Today, families, communities, nations, and humanity itself face multiple challenges for which scientific research can improve or save millions of lives. The need for science is great. But, many beneficial avenues of scientific inquiry are expensive – including those avenues of inquiry that can produce highly valuable public goods.

Governments have stepped in to mitigate free-rider problems in science. That fact makes the government -- and in democratic societies, the public – patrons of science. However, attitudes about science's value are shifting among these patrons (American Academy of Arts and Sciences 2018). About 50% of Americans surveyed, for example, agreed with the statement "science makes our way of life change too fast" (National Science Board 2018). Others see partisan, ideological and other trends that threaten to undermine science's credibility (Pielke Jr 2006, Bolsen and Druckman 2015) and cultural authority as a means of producing vital knowledge (Suhay 2017). Increasingly, people are asking questions such as "why should we trust science" and "why should we pay for research at elite universities."

In this paper, we use formal models to explain how the people responsible for making funding decisions will respond to these and other changes. We explain why politicians pay (or do not pay) for certain kinds of research. We also explain how government support for research is likely to change in the years to come. In particular, we anticipate that in fields where other public or private sector organizations can provide seemingly comparable information, government is likely to make different kinds of demands that they have in the past.

In such cases, an effective case for continued public support of scientific activity depends on researchers' abilities to answer the questions "does the activity provide benefits that are more valuable than the resources that are allocated to it?" and "does the activity provide benefits that are more valuable *than the other activities to which those resources could be allocated?*" Answers to these questions depend on the activity having attributes that allow it to create distinctive social value.

Individual researchers and research entities can sustain or increase demand for their work only if they can demonstrate that this work produces benefits that are large with respect to its costs *and in comparison to its competition*. Therefore, if scholars or research entities want more opportunities to pursue discovery, inform policy, make money, or have satisfying jobs, they will need to respond to increasing competition from "exogenous factors" and the changing demands of funders that such competition can bring.

Effective responses can take several forms. The key is to adapt in ways that *increases the apparent value of scientific work to key societal stakeholders*. Relevant competences include:

- *communication training* that helps researchers explain their work in ways that are both accessible and accurate,
- *transparency practices* that allow science consumers to better understand what findings do—and do not—mean, and
- committing to *greater knowledge of what stakeholders need* – which may entail shifting the content of proposed research funding portfolios (see also Lupia 2017).

People who became accustomed to the science funding norms of an earlier era may resist these ideas. To such resistance, we say again, with empathy, "everything" can't be funded. "Everything" is infinite. Funding is finite. So, tradeoffs of real options against real options must be made. For an increasing number of research entities, ignoring patrons' concerns is no longer viable.

If decision makers in increasingly competitive information and funding environments see particular kinds of research agendas as helping them to advance their goals, they will gain the persuasive power and leverage that they need to build needed supportive legislative coalitions. To this end, improving communication and engaging more effectively with stakeholders is about more than asking for money. The reason to engage is not to seek advice on scientific practice; it is to seek counsel about what kinds of work make valuable insights more likely and what type of insights give funders the leverage they need to continue to support scientific activities. Such engagement can change public perceptions of our work, increase the efficiency with which we serve others, and increase the conditions under which hard working researchers can conduct transformative basic research and produce currently unimaginable public goods. We hope that this paper informs and inspires others – particularly those whose ambitions include building next generation miracle machines – to adapt effectively to the changing circumstances now being faced by research entities of all kinds.

References

American Academy of Arts and Sciences. 2018. *Perceptions of Science in America: A Report from the Public Face of Science Initiative.* https://www.amacad.org/publicfaceofscience/PFS.html

American Institutes for Research. 2014. *The Nonacademic Careers of STEM PhD Holders.* http://www.air.org/sites/default/files/downloads/report/STEM%20nonacademic%20careers%20 April14.pdf.

Bolsen, Toby, and James N. Druckman. 2015. "Counteracting the Politicization of Science." *Journal of Communication* 745- 769.

Brandenburg, Karlheinz, and Gerhard Stoll. 1994. ISO/MPEG-1 Audio: A Generic Standard for Coding of High-Quality Digital Audio. *Journal of the Audio Engineering Society* 42:780-792.

Cantor, Eric and Lamar Smith. 2013. "Rethinking Science Funding." *USA Today*, September 30. http://usat.ly/JrdwZU.

Chronicle of Higher Education, The. 2014. "25 Years of Declining State Support for Public Colleges." https://www.chronicle.com/interactives/statesupport

Ellison, Glenn. 2002. "Evolving Standards for Academic Publishing: A q-r Theory." *Journal of Political Economy* 110: 994-1034.

Gailmard, Sean, and John W. Patty. 2012. “Formal Models of Bureaucracy.” *Annual Review of Political Science* 15: 353-277.

Lander, Eric S., and Eric E. Schmidt. 2017. “America’s Miracle Machine is in Need of, Well, a Miracle.” Washington Post, May 5. http://wapo.st/2pPzm1y?tid=ss_mail&utm_term=.7e9cde985be8

Lupia, Arthur. 2014. “What is the Value of Social Science? Challenges for Researchers and Government Funders.” *PS: Political Science and Politics* 47: 1-7.

Lupia, Arthur. 2017. “Now is the Time: How to Increase the Value of Social Science.” *Social Research: An International Quarterly* 84: 689-715.

Mervis, Jeffrey. 2015. “NSF Peer Review Remains Target for Congress.” *Science*, October 8. doi:10.1126/science.aad4690.

Mervis, Jeffrey. 2017. “Rand Paul Takes a Poke at NSF Peer Review Panels.” *Science*, October 19. doi:10.1126/science.aar2630

National Academy of Sciences. 2016. “From Research to Reward.” http://www.nasonline.org/publications/from-research-to-reward/

National Science Board. 2018. *Science and Engineering Indicators (2018).* https://www.nsf.gov/statistics/2018/nsb20181/

National Science Foundation. 2010. *Grant Proposal Guide. Chapter II: Grant Administration.* https://www.nsf.gov/pubs/policydocs/pappguide/nsf10_1/aag_2.jsp

Olson, Mancur. 1965. *The Logic of Collective Action: Public Goods and the Theory of Groups*. Cambridge, MA: Harvard University Press.

Patty, John W., and Elizabeth Maggie Penn. 2014. *Social Choice and Legitimacy: The Possibilities of Impossibility*. New York: Cambridge University Press.

Pielke Jr, Roger A. 2006. "When Scientists Politicize Science." *Regulation* (Spring) 28-34.

Schroeder, Manfred R., Bishnu Atal, and Joseph Hall. 1979. "Optimizing Digital Speech Coders By Exploiting Masking Properties of the Human Ear." Journal of the Acoustical Society of America Vol. 66: 1647-1652.

Suhay, Elizabeth. 2017. "The Politics of Scientific Knowledge." *Oxford Research Encyclopedia of Communication*. DOI: 10.1093/acrefore/9780190228613.013.107

Smith, Lamar. 2017. "Science That Leads: The National Science Foundation Needs to Get its Priorities Straight." *Roll Call* (November 30). https://www.rollcall.com/news/opinion/national-science-foundation-china