Accelerating Actionable Sustainability Science
Science Funding, Co-Production, and the Evolving Social Contract for Science

by

James C. Arnott

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Doctoral Committee:

Professor Maria Carmen Lemos, Chair
Professor Joe Árvai
Professor Rosina Bierbaum
Professor Richard Rood

James C. Arnott

arnott@umich.edu

ORCID iD: 0000-0003-3989-6724

Dedication

In memory of my mother, Patricia Casey Arnott (1946-2018),
who always anticipated a brighter future.

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Abstract

Disruptions to our climate and other systems critical to sustaining life on Earth increasingly call for aggressive societal action. Science can help inform these actions, yet a gap between scientific knowledge production and use persists. Whereas science has traditionally separated itself from society, alternative models of producing science seek out inspiration from societal needs and interact with potential users during the research process. Previous studies indicate more engaged and collaborative approaches to producing science, or *co-production*, can generate more actionable scientific knowledge while also enabling more inclusive research cultures. Despite growing inclination across the science system to co-produce knowledge, it remains unclear how co-production will contribute at the speed and scale demanded by unfolding crises in climate and sustainability. For example, scaling up co-production must attend to its potentially high costs, navigate diverse inputs of expertise, perspectives and values, while at the same time demonstrating meaningful progress on solutions.

This dissertation contributes new, more extensive empirical data and analysis about the drivers and mechanisms of co-production with the aim to better understand how to accelerate the development of actionable sustainability science. Going beyond the existing case-specific literature, I investigate a large number of applied research projects and science funding programs to explore the role of public funding as a mechanism for changing the way science is produced and used. Specifically, I ask three questions:

1) Can funding requirements that encourage more interaction between scientists and users lead to an increase in scientific knowledge co-production?

2) To what extent do research practices, especially those related to co-production, result in more knowledge use?

3) To what extent is science funding already reshaping the way science engages with society?

In the first half of the dissertation, I create a new database of coastal and estuarine research projects (n=120) and conduct interviews with grantees and intended users (n=40). This data shows how funding program design changes that require collaboration with users cultivate the practice of co-production, resulting in more intensive interactions and increasing evidence of knowledge use over time. I also find that this more deliberate effort to fund and co-produce usable science does not, on its own, help overcome the longstanding methodological obstacles that its study entails. In the second half, I explore the wider landscape of public science funding. First, I review recent science policy literature about what types of funding program design changes may influence research practice and outcomes. Then, I analyze science funding program solicitations (n=33) and interview program managers (n=61) in the U.S. and Europe. This fieldscan depicts science funders actively considering how science best engages with society and deploying numerous strategies that could reshape underlying societal expectations for science.

Overall, this dissertation documents a transition toward collaborative models of research practice and sponsorship, an evolution that may accelerate progress in linking science with solving sustainability problems. Capitalizing on future opportunities for learning through experimentation with different research modes and funding styles is still necessary to advance a more practice-relevant science of actionable knowledge.

Chapter 1. Introduction

1.1 *The need to mobilize science for action*

Scientific research has made great strides in understanding the drivers and consequences of global environmental change. Perhaps the most consequential uncertainty remaining is how, and how quickly, society will act in response. While few people today are altogether unaffected by the consequences of climate change, biodiversity loss, and other forms of environmental disruption, a growing many are starting to more acutely realize the physical, financial, and emotional harm resulting from these impacts (Bloomberg, Paulson, & Steyer, 2014; Coyle & Van Susteren, 2011; IPBES, 2019; IPCC, 2018; USGCRP, 2018). Addressing the root cause of these disruptive changes, managing risks wherever they are unavoidable, while at the same time pursuing sustainability goals is the task at hand for 21st century society (Harvey, Orvis, & Rissman, 2018; Matson, Clark, & Andersson, 2016; Moss et al., 2019). Many that have considered the actual scope of this task conclude that successfully completing it will entail fundamental changes within social, political, and economic institutions (116th U.S. Congress, 2019; IPCC, 2018; Raworth, 2017; Thurnberg, 2019). The institution of science, too, will likely have to change (Wyborn et al., 2019). But how precisely should science change? And how can it change so as to meaningfully contribute to environmental and sustainability problems at the requisite speed and scale?

The way the scientific community organizes to produce new knowledge has never been static, but since the end of World War II a seemingly stable approach emerged (Sarewitz, 1996).

Scientific organizations have operated with a high degree of independence from other societal institutions, and they typically separate the work to produce new knowledge from the efforts to apply it. As justification, the history of science provides a trove of examples where discoveries initially achieved without motivation for practical application—Maxwell's equations, Bohr's law, Einstein's theory of relativity—later became essential to the everyday functioning of society (Flexner, 2017). Public funding organizations have helped to sustain this more autonomous configuration for science, albeit with the expectation of eventual societal benefits in return (Stokes, 1997). And in many ways this approach has delivered: revolutionary breakthroughs like Google's search algorithm, mapping the human genome, and GPS all came to fruition through the curiosity-driven and relatively undirected domain of basic research (PCAST, 2012). No less astounding are the fundamental advances in understanding Earth system processes, also largely made within this context, which have helped society to understand the speed and scale of looming planetary-wide challenges (Meehl & Moss, 2016; Steffen et al., 2018; USGCRP, 2017).

However, the demonstrated use of environmental and sustainability knowledge to inform action is less than many desire or expect (Clark, van Kerkhoff, Lebel, & Gallopin, 2016; Moss et al., 2019; NRC, 2010; NRC, 2009; Sarewitz & Pielke, 2007; USGCRP, 2012; GAO, 2015). Accordingly, leaders in science and society have increasingly vocalized the need for science to do more to inform, and even catalyze, the kind of aggressive action the speed and scale of this challenge requires (Lubchenco, 2017; Moss et al., 2019). In other words, there is an impetus for more actionable science (Asrar, Hurrell, & Busalacchi, 2013; Beier, Hansen, Helbrecht, & Behar, 2017). Scholarship investigating the knowledge-to-action gap and how to narrow it, particularly in the environmental domain, points out ways in which the 20th century approach to research may serve as a barrier to producing the kind of decision-relevant, accessible, and credible science that would be more readily usable (Lemos, Kirchhoff, & Ramprasad, 2012; McNie, 2007). Unsurprisingly, separation between basic science and its application, and between scientists and users, creates and instills institutional, cultural, linguistic, and technical barriers that limit knowledge uptake (Caplan, 1979; Jacobs, Garfin, & Lenart, 2005; Lemos et al., 2012).

An increasingly common idea for how to bridge gaps between sustainability science and action is to conduct research more collaboratively with those expected to utilize it to make decisions or implement actions (Beier et al., 2017; Lemos & Morehouse, 2005). Such interactive approaches incorporate expertise from those with deep knowledge about the context of application and may involve people such as elected decision-makers, professional resource managers, sustainability professionals, and other practitioners charged with implementation. Studies where these interactive and engaged approaches to research have been employed report an increase in the likelihood that research outcomes are relevant and perceived as credible, thus fostering improved conditions for utilization (Cash et al., 2003; Dilling & Lemos, 2011; Fujitani, McFall, Randler, & Arlinghaus, 2017). While optimism about these outcomes has motivated an expanding set of fruitful collaborations between research and practice in different sectors (see Box 1 for one example in water resource management), there has also been growing attention to their high cost

Box 1. Science with and for water utilities

One example of research-practice interaction has been an ongoing set of collaborative research activities between a dozen of the largest water utilities in the United States and climate modelers and hydrologists. Beginning in 2008, water utility staff have worked alongside researchers to interpret existing research and develop new analyses that seek to portray changes to climatic parameters that could influence future decisions on infrastructure investment, operations, and long-term planning (Vogel et al., 2016). While this unfolding effort has demonstrated success in producing actionable knowledge and reshaping how utilities think about and plan for the future, the process has entailed substantial time as well as cost in terms of time and effort of all participants. Case examples such as this illustrate the potential of more collaborative approaches to increase the usability of science, but it remains unclear how they might scale, or what to expect as these practices become more mainstream (Lemos et al., 2019). The fact that there are 55,000 other utilities in the United States highlights the scope of the challenge of scaling in just one sector (Office of Water, 2008) not to mention the myriad context-specific issues likely to demand attention in other scales and regions (Moss et al., 2019).

in terms of time and other resources (Lemos, Kirchhoff, Kalafatis, Scavia, & Rood, 2014; Lemos et al., 2019; Trainor, Kettle, & Gamble, 2016). Thus, more collaborative means to producing science to support societal goals related to sustainability must be considered within the context of how they can scale up to the speed and scale demanded by the nature of the challenge.

1.2 *Making sense of science usability, co-production, and the social contract*

First, we must first come to terms with terms. This dissertation pivots around three concepts: usable science, co-production, and the social contract for science. The terminology surrounding these concepts is sufficiently ambiguous, variously utilized and defined, that I wish to introduce each briefly here to convey their meaning within the context of this dissertation.

I define usable science as scientific information, tools, and products that can be utilized outside the context of research to inform decision-making and action. For the purposes of this dissertation, usable science is synonymous with actionable science, though usage varies by chapter. All forms of knowledge possess intrinsic value (Holbrook, 2018), and some forms of knowledge that at first appear to be useless eventually become essential for practical ends (Flexner, 2017). However, usable science is readily capable of being used. In the context of global change research in the United States, usability is enshrined in the foundational legislation that justifies and coordinates its public financial support. The US Global Change Research Act of 1990 offers a kind of prime directive for this research enterprise to "*provide usable information* on which to base policy decisions relating to global change" (101st US Congress, 1990; emphasis added). Beyond the law, this aspiration is reflected in many historical and contemporary statements by scientists, scientific organizations, and funding programs worldwide (Future Earth, 2014; Rockström et al., 2015; Vano, Behar, Mote, Ferguson, & Pandya, 2017). Indeed, many individuals and organizations across the scientific enterprise are motivated to provide a meaningful service to society in the form of usable knowledge. However, the relationship between science and decision-making is complicated by the presence of numerous individual and institutional factors that influence when, if, and how any new piece of knowledge is utilized. These complications constrain both producing usable knowledge and knowing when and how knowledge is used to what end. As a result, scholars of science (Lemos et al., 2012; McNie, 2007; Sarewitz & Pielke, 2007), program evaluators (GAO, 2015; Wall, Meadow, & Horganic, 2017), practitioners (Asrar et al., 2013; Beier et al., 2017), and many scientists have lamented that global change research is not as usable as it could, or should be. In response, many identify, or advocate for, strategic efforts at institutional levels to address the usability gap (Asrar et al., 2013; Kirchhoff, Lemos, & Dessai, 2013; Moss et al., 2019; NRC, 2011; USGCRP, 2012).

Scientific knowledge co-production (hereafter, co-production) is one such strategy. In the context of this dissertation, co-production refers to deliberate and meaningful interaction between scientists and potential users of science to *co*llaboratively *produce* scientific knowledge (Lemos & Morehouse, 2005). Co-production has become an increasingly elevated strategy for increasing the likelihood that research results are utilized. For example, many researchers and users who co-produce research to inform water utility management (see Box 1) advocate for its expanded practice to produce more usable knowledge (Beier et al., 2017; Vogel, McNie, & Behar, 2016). But despite the promise of co-production, scaling co-production effectively—and equitably—requires much work to attend to the distribution of privilege and power amongst its participants and stakeholders (Klenk et al., 2015), to understand how best to evaluate its processes and outcomes (Meadow et al., 2015; Wall et al., 2017), and to cover its costs in terms of time, effort, and financial expense (Kettle & Trainor, 2015; Lemos et al., 2019).

Finally, since the science system heavily relies on public funding, the social contract refers to expectation that science will produce societal benefits in return (Gibbons, 1999). A gathering chorus of scientists and policy-makers in the environment have called upon the scientific community to attend more closely to this expectation and deliver on this commitment (Castree, 2016; DeFries et al., 2012; Lubchenco, 1998, 2017). Science policy research examines many types of public benefits of scientific research, particularly in the domains of economic competitiveness, technological innovation, national security, and medicine (NRC, 2014). Although the potential societal benefit of advancing science for policy and decision-making in the area of sustainability and environment is enormous, less attention has so far been devoted to studying how changes in science structures, such as funding approaches, could influence these types of public benefits (Bozeman & Youtie, 2017).

1.3 ***Accelerating actionable sustainability science***

Data on numerous social and environmental trends show that our world is in the midst of a "Great Acceleration," where the influence of human activities on planetary systems is growing at considerate speed and scale and, without course correction, will likely outstrip planetary limits (Rockström et al., 2009; Steffen, Broadgate, Deutsch, Gaffney, & Ludwig, 2015; Steffen et al., 2018). Thus, any type of strategy seeking to meaningfully contribute to this challenge must consider how its approach to system intervention can also accelerate and scale up. The focus of this dissertation, therefore, explores the overarching question of how the scientific enterprise can scale up—and accelerate—the ability for science to inform decisions and actions in response to global sustainability and environmental challenges. Given the growing desire to increase the use of sustainability and global change science, and the growing popularity of co-produced research as one means to this end, there is now a critical opportunity to understand more about how changes in how we do science may strengthen the link between science and action.

Pursuing, or stubbornly resisting, changes in how we do science should not be done willy-nilly. As one interviewee during my research told me, ***"you can take 50 years to build an orchard and take an afternoon to cut it down."*** Like disruptions to other critical social institutions, implementing changes in science, without care to safeguarding fundamental system functions, could do more harm than good. Furthermore, in our seemingly post-truth era where wanton pursuit of disruptions to critical institutions has become more commonplace (Latour, 2018), making changes to science on the basis of reason and evidence, rather than whim or short-term interest, may now be more important than ever.

Science, like other human endeavors, is amenable to the systematic study that social scientific inquiry can offer. My dissertation applies documentary analysis and interviewing methods to examine instances where change is happening in the way the scientific enterprise is organized. My aim is to understand more about the drivers of those changes and their impacts on how scientific knowledge is produced and used. In particular, I focus on science funding organizations, both as a way to gain access to relevant data on reported research practices and outcomes and to study funders themselves as drivers of scientific knowledge use. Accordingly, this work seeks to tackle three questions:

1) Can funding requirements that encourage more interaction between scientists and users lead to an increase in scientific knowledge co-production?

2) To what extent do research practices, especially those related to co-production, result in more knowledge use?

3) To what extent is science funding already reshaping the way science engages with society?

In pursuing these questions, this research produces new evidence that further explains the role funders of science can play in shaping research practice and how shifts in research practice toward co-production can yield gains in knowledge use. Results also provide more specific detail about how and why some funding programs have changed and what those changes could mean for the relationship between science and society.

The dissertation consists of two major projects. The first project examines a single environmental science funding program over 16 years of its transition from a traditionally configured research funding program to a fully-fledged sponsor of knowledge co-production. This program, the competitive grant funding arm of the National Estuarine Research Reserve System, affords a unique natural experiment in funding research for use. That is, the program's continuous goal was to produce knowledge and tools that could be utilized by coastal and estuarine research managers, but the program's approach to achieving this goal evolved through successive generations of program design changes. This allows for testing how attributes of research practice and evidence of use vary across traditional and alternative structures for supporting and conducting research.

In Chapter 2, I analyze 120 project reports from a 16 year period of this program's history and interview 40 grantees and users to evaluate how changing program requirements influence research practice and how a programmatic strategy to encourage more interactive research influences use. I find that changes in competitive funding program design and requirements at the National Estuarine Research Reserve System were able to achieve significant increases in the intensity of interaction by their grantees with users. Along the way, grantees did not only substantively comply with requirements but there were also significant increases in the likelihood research results were utilized. In depth interviews with some grantees portrayed a marked shift in attitude toward embracing the benefits of more collaborative research cultures. This attitude was found to endure, even long after the conclusion of their funded work and, for some, persist throughout future research projects.

Chapter 3 builds upon the preceding chapter by more critically exploring how grantees characterize, track, and attribute use, users, and the broader outcomes from their research. I identify how methodological challenges for the study of use persist even amid more deliberate attempts to drive use through the practice of co-production. I find a tension between the enthusiastic adoption of the process of more collaborative research modes and the challenge of describing the impact of this process on the usability or other benefits of the research. More generally, I find that limits to how actors across the landscape of funding, research, and practice understand and evaluate usability constrain the potential insight we could gather from experiences where usable knowledge is deliberately pursued. Moving forward, more research about knowledge use conducted along with funders, sustainability scientists, & users could help address these conceptual and methodological limitations to further advance the science of actionable knowledge.

In the second project, I take a more wide-angle view of the science funding landscape. In Chapter 4, I review a broad range of science policy literature to explore how the management of science funding has influenced research practice and outcomes, especially the creation of actionable knowledge. Prior investigations into this issue, while limited, suggests four areas of opportunity funders may consider incorporating into their program management, including: 1) incentivizing engagement through research solicitation guidelines and criteria, 2) facilitating appropriate expertise and user input into proposal review, 3) providing project implementation support, and 4) fostering learning about actionable knowledge through evaluation.

In Chapter 5, I further explore these opportunities and the extent to which they are being pursued and why. I assemble a database of 33 program solicitations and interview 61 individuals working in the area of program management for public science funding in the domain of Earth, environmental, and sustainability research across the US and Europe. The resulting analysis of interviews and program documents track the ways in which science funding programs are changing and explain more about the role of program management in influencing this change. The results suggest how a funder's program management style and expectations for societal impact from science influence the kind of relationship between science and society that their funding would support. These different configurations, including the deliberate pursuit of actionable science, present different ways of interpreting, and possibly serve to reshape, the social contract for science. I also find that despite many potential types of program innovation being pursued by funders, there has been less investment to evaluate the non-economic societal benefits of research in ways that would further understanding of impact.

Finally, in the concluding section, I reflect upon my own journey at the interface of science and practice and summarize the findings of this dissertation for a general audience, including specific recommendations for science policy makers and science funding program managers.

Chapter 2. Driving Knowledge Use for Sustainability

This chapter is based on the following publication: Arnott, J. C., Neuenfeldt, R. J. & Lemos, M. C. (in press), Co-producing science for sustainability: Can funding change knowledge use?, *Global Environmental Change.*

2.1 *Introduction*

Identifying how science can best help society manage risk and solve sustainability problems remains a grand challenge for practitioners, scientists, and funders. Meeting this challenge may require systemic changes to the way research is practiced, funded, and disseminated. But making changes to the scientific enterprise while preserving its ability to generate new knowledge and societal value requires more evidence as to what drives scientific impact. This study analyzes new empirical data about how science funding requirements for interaction between researchers and users can increase the use of scientific knowledge for environmental decision-making. In particular, we test how changes in funding program structure shape scientific practices and how such changes may lead to increased use of scientific knowledge.

Scholars have long speculated that a gap between the science and policy communities in their norms, language, incentives, and goals works as a barrier for the use of scientific knowledge (Caplan, 1979). Accordingly, there has been growing interest in how the co-production of scientific knowledge can help to narrow this usability gap. However, scientific knowledge co-production (hereafter, ‘co-production’) itself is not without controversy, ranging from different conceptualizations of what co-production means to divergent ideas for realizing goals and evaluating outcomes (Lemos et al., 2018; for a rich discussion on different definitions of co-production, see Bremer & Meisch, 2017). And while studies have shown that interaction between research and practice fosters improved use across various environmental research settings (Cash et al., 2003; Dilling & Lemos, 2011; Fujitani, McFall, Randler, & Arlinghaus, 2017; Vogel, McNie, & Behar, 2016), others have warned about the need to fully attend to issues of equity and ethics in co-production (Klenk et al., 2015). Whether inspired by the evidence of increased use, or perhaps by deeper aspirations for a more inclusive and collaborative research culture, many funders, researchers, and practitioners across environmental research domains are keen to pursue co-production, which they often define as a meaningful interaction between these communities (Asrar et al., 2013; Beier et al., 2017; Vano et al., 2017).

Yet, despite promising reports about co-production and related approaches, the evidence base about how it drives use remains relatively sparse and context dependent (Posner & Cvitanovic, 2019; Wall et al., 2017). Furthermore, to the extent that co-production works, more insight is needed about how to scale it up both across different scientific fields and contexts of application. As influential organizations well-poised to collect relevant data, funding agencies may play an important part in building this evidence base. However, existing science policy research presents mixed evidence about the influence of funders on the practice of science and offers little on the question of what drives it. While some studies reported benefits of funding approaches that encourage interaction with various practitioners (e.g., DeLorme, Kidwell, Hagen, & Stephens, 2016; Moser, 2016), others are concerned with unintended consequences and perverse incentives arising from interventions by funders (Lövbrand, 2011). Finally, studies also point to researchers sidestepping changes in rules to maintain the status quo in spite of the best laid plans of funders and science policy-makers to effect change in research practices (Davis & Laas, 2014; Holbrook, 2012; Reale & Zinilli, 2017).

In this chapter, we analyze research projects funded by the National Estuarine Research Reserve System (NERRS, a program of the U.S. National Oceanic and Atmospheric Administration-- NOAA). Over the period between 1998-2014, the program periodically increased requirements for collaboration between researchers and coastal managers. This history affords a rich database for testing the hypotheses that funding can stimulate co-production and that co-production increases knowledge use. Using this data, we ask:

1. Can funding requirements that encourage more interaction between scientists and users substantively influence research practice?

2. Can changes in research practices, especially those related to co-production, result in more knowledge use?

We investigate four distinct generations of funding administered by NERRS, wherein each progressively requires more co-production interaction by the grantees. By comparing each generation against the initial one—which closely approximates a traditional model of research funding and practice wherein funders allocate resources to scientists for largely independent investigations—we are able to study the shift toward more impact-oriented science funding. Using data from 120 final project reports and 40 interviews we find significant changes to research practice resulting from funding program design. We also find that more intensive interaction between researchers and users significantly increases the likelihood of use.

We organize this chapter as follows. Section 2.2 describes knowledge co-production as a general strategy to increase the use of environmental knowledge, briefly reviews existing evidence about funders' influence on research practice, and introduces the National Estuarine

Research Reserve System as the focus of our study. In Section 2.3, we present a detailed accounting of our mixed research methods approach, the results of which are presented in Section 2.4. Section 2.5 discusses these findings and their implications, and in 2.6 we state our conclusions. The appendix provides a detailed codebook (A-1), interview guide (A-2), additional coding results and analysis (A-3&4), and coding data (A-5).

2.2 ***Background***

2.2.1 Knowledge co-production & research use

The assumption that science produces more societal benefits through intensive interaction with non-scientists challenges a long-held expectation that science serves society best when working in relative independence. Yet scholars of science have often described scientific knowledge as being unavoidably shaped and reshaped through interactions between scientists and the society in which they work, a process termed co-production (Jasanoff, 2004). When defined as a form of "iterative interaction," knowledge co-production can also refer to research-practice collaboration during one or more phases of the research process such as study design, implementation, analysis, or dissemination (Bremer & Meisch, 2017; Cash, Borck, & Patt, 2006; Meadow et al., 2015; Michaels, 2009; Reed, 2008). In environmental research, this more instrumental sense of co-production has recently diffused more widely by advancing the idea that increased interactions between research and practice will increase knowledge use (Lemos & Morehouse, 2005). The extent and type of interaction may take on different forms and intensities (Klenk et al., 2015; Trencher et al., 2017), and a variety of other benefits may emerge, including more participatory or inclusive approaches to science. Furthermore, the use of the term co-production may encompass or overlap with other strategies such as co-design (Mauser et al., 2013), research-practice partnerships (Tseng, 2012), transdisciplinary research (Lang et al., 2012), and collaborative research (Matso, Dix, Chicoski, Hernandez, & Schubel, 2008).

There is growing evidence that this more deliberate form of co-production drives research use. For example, David Cash and colleagues (2003) found that environmental assessments generated through some form of interaction between research and practice were more likely to be used. Similarly, Dilling and Lemos (2011) suggest that there is higher likelihood that seasonal climate forecasts will be used if co-produced between providers and potential users. In a large scale experimental study, Fujitani and colleagues (2017) showed how local fishery managers retained new knowledge better and were more likely to pursue sustainable resource management practices when scientists interacted with the managers rather than merely presenting them with information. And for now over a decade, climate scientists, hydrologists, and water managers have explicitly embraced co-production as a strategy to develop climate and water projections to support long-range planning (Vogel et al., 2016), leading some of the involved practitioners to advocate for a more widespread practice of co-production (Beier et al., 2017).

However, gaps remain in understanding how to overcome institutional barriers that hinder co-production's appeal and use (Briley, Brown, & Kalafatis, 2015; Moser, 2016; Wall et al., 2017). Barriers to co-production include the intensive investment of time and other resources required by and from participants (Lemos et al., 2014), which can sometimes be exacerbated by low expectations and fatigue from non-researchers (Briley et al., 2015; Newton & Elliott, 2016). Moreover, while co-production is often predicated on the assumption that closer interaction between research and practice is necessarily better, it remains unclear how the outcomes of co-production can be achieved at scale, especially if so reliant on repeated in-person interaction and trusted relationships. For example, social experiments testing virtual and asynchronous options for interaction raises new questions about when and how to invest time and resources into face-to-face interaction (Kettle & Trainor, 2015; Lemos et al., 2019).

Both practical challenges and normative concerns arise in the linking between scientific knowledge co-production and use. From a practical standpoint, there are persistent methodological issues that constrain the ability to study the use of scientific knowledge as a phenomenon (Landry, Lamari, & Amara, 2003; Larsen, 1981). Most significant are the multiple ways of defining use as an outcome variable. Defining use can range from a binary construct of use and non-use (Ryan & Gross, 1943) to a multi-level variable that mirrors various opportunities of knowledge use in decision-making (Knott & Wildavsky, 1981). A typology introduced by Pelz (1978) distinguishes use between *instrumental* (i.e. direct use in problem solving), *conceptual* (i.e. informing awareness, enlightenment), and *symbolic* (i.e. supporting pre-determined positions or decisions). However, scholars have argued that any typology can be difficult to operationalize in systematic studies (Gitomer & Crouse, 2019). Furthermore, there are other practical challenges, such as the challenge of would-be users recalling what knowledge they draw upon for decisions and why (Spaapen, Shinn, Msh-paris, & Marcovich, 2013) and making research design choices regarding the range of factors that could explain utilization (Landry et al., 2003).

Of more fundamental concern to some is the growing emphasis by funders, policy-makers, and researchers on the usability of science. Though breakthrough discoveries may occur through use-inspired science, as observed in Donald Stokes' classic text *Pasteur's Quadrant*, many innovations that eventually serve practical ends emerge when consideration of use is low (Stokes, 1997). In the introduction to the essay *Usefulness of Useless Knowledge*, Robbert

Dijkraff (Flexner, 2017) articulates a concern we now frequently hear vocalized in different quarters of the scientific community:

> Driven by an ever-deepening lack of funding, against a background of economic uncertainty, global political turmoil, and ever-shortening time cycles, research criteria are becoming dangerously skewed toward short-term goals that may address immediate problems but miss out on huge advances that human imagination can bring in the long term. (p. 10)

Reasonable arguments such as these strengthen the rationale to increase the evidence base to guide interventions in research practice. Similar to our lack of broad, generalizable understanding about what factors drive knowledge use, expectations about the value of undirected research could be as much a function of longstanding research culture as of an understanding of what approaches are demonstrably better (Sarewitz, 1996). This study, therefore, aims to add to this ongoing discussion by providing evidence that does not invalidate the caution articulated by Dijkgraff and others, but does in our view offer evidence for how to accelerate the use of research on increasingly urgent societal problems related to global environmental change and sustainability.

2.2.2 Funder-driven changes to research practice

Funders of science may be in a key position to strengthen the evidence base for, and help implement, the kinds of practices that drive research use. Science policy research investigates changes in how research funding is structured and how that helps achieve societal goals. For example, studies evaluating the institutionalization of a Broader Impacts statement by the US National Science Foundation (NSF) found that few applicants considered engagement with users as a form of broader impacts and, on balance, researchers retained, as before, a high degree of autonomy (Holbrook, 2012). In a broader, comparative analysis, Davis and Laas (2014) contrasted the Broader Impacts funding approach of the NSF to the Responsible Research and

Innovation (RRI) framework applied through European Union science funding. They uncovered how subtleties in messaging within each approach shape their ultimate impact. For example, whereas RRI was found to stimulate changes in research culture with respect to societal interaction, Broader Impacts was found to preserve autonomy of researchers by letting them define the public benefits of their research on their own terms. In another example, Reale and Zinilli (2017) studied new approaches to the proposal peer review process enacted by a national funding program in Italy and found that reviewers side-stepped more structured approaches to proposal evaluation or interpreted them in sufficiently different ways than intended. As a result, the overall process remained much the same as before the restructuring.

While public funding of science in the United States has traditionally afforded researchers autonomy (Bush, 1945; Sarewitz, 1996), some funders have begun to shape program goals, guidelines, or requirements toward co-production with the aim of increasing research use. For example, in response to seed funding for research-practice collaboration on full proposals solicited by Future Earth, unanticipated research collaborations occurred across disciplines and institutional boundaries, even among proposal teams not awarded full funding (Moser, 2016). Similarly, when funders solicited user input to an RFP and involved them as advisors during funded projects, shifts in thinking were reported by users about the kinds of research most appropriate or relevant for their problems (DeLorme et al., 2016). Yet, other reports suggest success is not guaranteed and new approaches warrant caution. Ford, Knight, and Pearce (2013) analyzed research proposals in which co-production was not required but was implicit in the program's aspiration. In the end they found that a lack of explicit guidance or requirements meant that few proposals demonstrated even the intention to engage with users.

2.2.3 *Competitive funding in the National Estuarine Research Reserve System*

As a funder, the National Estuarine Research Reserve System (NERRS) has operated a nationally competitive funding program to generate usable research for coastal management since 1998 (Trueblood et al., 2019). NERRS was created by the Coastal Zone Management Act of 1972 as a network of research, stewardship, and educational centers based in ecologically sensitive coastal areas (92nd U.S. Congress, 1972). NOAA's National Ocean Service oversees the System of 30 reserves. Estuarine and nearby coastal regions face acute sustainability challenges due to complex ecosystem dynamics stemming from the combination of anthropogenic pollution, sea level rise and other impacts (Allison & Bassett, 2015). Understanding the causes, consequences, and potential options for these kinds of risks is an active area of research and a key concern for resource management and planning at local, state, and national levels (Tribbia & Moser, 2008; Ultee, Arnott, Bassis, & Lemos, 2018). Included in Figure 2-1 are example project titles funded by NERRS over time.

Previous research focusing on NERRS suggests the program to be a fertile setting to study scientific practice and use. For example, based on a survey of projects between 1997-2006 Riley and colleagues (2011) identified opportunities for more in-depth consideration of a sponsor's role in generating usable science but also pointed to the insufficiency of available resources to support the long-term cost of successful interaction. Similarly, in-depth qualitative case studies by Matso and Becker (2013, 2014) found changes in program direction enabled scientists to interact with users though program resources were ultimately insufficient to fully support those interactions.

2.3 *Methods*

To understand drivers of scientific knowledge use, we created a database of 16 years of projects funded by NERRS. First, we reviewed requests for proposals to identify major breakpoints in program design, which we call generations (see Figure 2-1). Then, we conducted qualitative content analysis (Bernard, 2013; Miles, Huberman, & Saldana, 2014) to code 120 randomly selected final project reports on attributes of usable knowledge (see Table 2-1), interviewed project team members and users (n=40) to triangulate and add context to the results of the documentary analysis, and, finally, used the software package R to analyze results using logistic and ordinal regression models ("R," 2016).

2.3.1 Organizing NERRS as a Natural Experiment

During the study period (1998-2014), approximately 180 research projects were funded. A review of Requests for Proposals during this time period revealed four distinctive generations of program design, characterized by major changes in the guidelines and requirements within the program's annual Request for Proposal (see Figure 2-1). Our understanding of the program's history and the rationale for change was greatly enhanced by the perspective provided to us by a veteran program manager with extensive institutional memory of the entire study period. To create a stratified random sample across this time period, 30 projects from each of these generations were randomly selected for a total sample of 120 projects (for a more detailed description of the shifts in historical perspective see Trueblood et al., 2019). Figure 2-1 shows the four generations.

Generation		1 Loading Dock	2 Technology Transfer	3 Knowledge Systems	4 Collaborative Science	
Program logic	*Intramural competition at University of New Hampshire*	High quality S&T research will lead to eventual commercialization & use	Commercialization and use of S&T requires a multi-step approach of proof of concept, development, and then transfer	Knowledge use requires more comprehensive awareness of user context, such as factors that shape credibility	Collaboration between researchers and end-users enable use, and specialists in collaboration are required to support successful interaction.	*Competition management continues at University of Michigan*
Timeline	1997	'98 '99 '00 '01	'02 '03 '04 '05 '06	'07 '08 '09	'10 '11 '12 '13	'14
Program design	*Not reviewed for present study*	Nation-wide competition first encouraged ('98) and then required ('99-'01) to "discuss" project with appropriate Research Reserve and state coastal zone managers.	Multiple tracks of funding for distinct stages of S&T development are provided. Varying requirements for identifying and seeking input or support from endusers. Outreach indicated as an integral part of some projects.	Added requirements for identifying and seeking input or support from end-users. Examples and guidance provided in RFP.	A project co-lead focused on collaboration is required. Applicants must identify end users, describe collaborative approach, and corroborate relevancy of proposed focus.	*Not reviewed for present study*
Example Project Titles		• Identification and Assessment of Anthropogenic Eutrophication in Shallow Estuaries • Phosphate-Based Heavy Metal Stabilization and Reactive Barrier Technologies for [...] Dredged Materials	• Satellite Linked Hydrologic Sensor Platforms Networked for [...] Water Quality Monitoring • Evaluating Buoy-Deployed Seeding for Restoration of Eelgrass	• The StormWater Management Planning Tool [...] • Mitigating Shoreline Erosion Along the Hudson River Estuary's Sheltered Coasts	• Building the Capacity of Coastal Communities to Address Climate Change Risks Through the Use of Role-Play Simulations • Collaborative Planning for Climate Change Adaptation	*Not reviewed for present study*
Management	Cooperative Institute Coastal & Estuarine Environmental Technology @ University of New Hampshire				NERRS Science Collaborative @UNH	NERRS Science Collaborative @ U-M

Figure 2-1. Timeline of NERRS' competitive research funding program. The generations identified by the authors are explained by substantial changes in the program design and logic.

Generation 1: "Loading Dock." Between 1998-2001, NERRS solicited proposals from Federal and academic researchers, NGOs, and private industry to conduct research at NERRS sites in order to support the long-term conservation of the Nation's coastal and estuarine systems. During the pre-proposal stage, applicants were required to "discuss proposed project" with a NERRS site but no further formalized engagement was encouraged or required.

Generation 2: "Technology Transfer." Between 2002-2006, NERRS solicited ideas for research projects at different phases of development with an emphasis on technology. Small "proof of concept" projects were supported alongside larger "development" and, beginning in 2003, "technology transfer" projects, which emphasized application-focused activities. Additionally, during this period, the program began to require letters of support from potential users and changed review criteria to emphasize connections with users.

Generation 3: “Knowledge Systems.” Between 2007-2009, program managers consolidated technology development and deployment into a single track of funding and identified other topic-specific funding tracks using surveys of coastal managers. This period was initiated in part when program managers became aware of social science literature on knowledge use, particularly the work of David Cash and his colleagues (Cash et al., 2003) that emphasized the concept of “knowledge systems,” i.e. how interactions between producers and users of knowledge can create a context in which knowledge is more likely to be utilized. In a striking change of tone from earlier solicitations, the 2007 RFP begins: “Investigators funded by [this program] *must* collaborate with the coastal management and regulatory communities” (our emphasis). Beginning in 2008, a collaborative plan for research was required in the proposal.

Generation 4. “Collaborative Science.” Between 2010-2014, management of funding was reorganized into a new initiative called the NERRS Science Collaborative. In this generation, applicants were required to provide a detailed collaboration plan and designate a collaboration specialist as a co-lead of their project (for case study descriptions of these types of projects see Matso & Becker, 2013, 2014). Additionally, program managers invested substantial resources in providing guidance and personalized support to project teams on collaboration methods and troubleshooting.

2.3.2 Documentary analysis

To systematically evaluate each selected project, two study authors conducted qualitative content analysis of final project reports utilizing NVivo (Miles et al., 2014). The coding scheme (see Table 2-1 for summary and A-1 for detail) was based on attributes related to research practice and use that stem from literature on knowledge co-production and research utilization. These included characteristics such as project activities and outcomes (Meadow et al., 2015), decision relevance (Moss, 2015), the readiness of users and the research of research for utilization (Bechhofer, Rayman-bacchus, & Williams, 2001), science-user interaction intensity (Klenk et al., 2015), flow of information between researcher and practitioner communities (Meadow et al., 2015 citing Biggs 1989), and dissemination strategies (Reed, 2008). With exception of the coding cluster for Use, all coding involved two authors, who coded independently and met regularly to discuss and reconcile differences. Codes developed for this study are “high-inference themes” in the sense described by Bernard (2013, p. 545). That is, each of the attributes entailed coder judgements based on texts that usually did not directly provide direct evidence. To ensure consistency in coding over course of the research process and between documents, a second cycle of coding was completed by the two coders, which produced a final set of coding results for analysis. Due to resource limitations, an exception to the two-coder approach was made during the coding for the variable, Use. Here, one author employed a secondary coding methodology, where passages previously tracked by two coders for User Readiness and Research Readiness were reexamined to assess use. Because judgements pertaining to use originate from sections initially coded on user readiness and research readiness, we excluded those attributes from statistical models that examine the outcome variable, Use.

Table 2-1 Abbreviated coding guide (see A-1 for expanded coding rubric)

1. Research Aims	Primary aim of project (produce new data or science, develop technology, test application of knowledge or tools, learn from users, build capacity) (Meadow et al., 2015).	**6. Use**	Evidence for use (non-use, indeterminate, use) and type of use (conceptual, instrumental) (Pelz, 1978)
2. Research Origins	How research questions and research designs were developed (by researchers, users, in combination) (Meadow et al., 2015).	**7. Direction of Communication**	How communication with users occurred (none at all, one-way, one-way with occasional consultation, or two-way) (Meadow et al., 2015). *See A-3 for results.*
3. Decision/ Management Relevance	Amount of detail (none, generic, specific) provided by researchers about decision-making or resource management context and criteria (Moss, 2015).	**8. User Involvement**	The way in which user involvement was situated in the project (none, passive, active) (Klenk et al., 2015; Meadow et al., 2015). *See A-3 for results.*
4. Dissemination	Venues and approaches to disseminating research findings (none, typical academic, loading dock (i.e. passive), active outreach to users, co-development of outreach with users) (Cash et al., 2006; Reed, 2008).	**9. User Readiness**	The ability of end users to apply research findings or products (Bechhofer et al., 2001). *See A-3 for results.*
5. Interaction Intensity	The extent of interaction between researchers and users (none, linking, match-making, collaborating, co-producing) (Klenk et al., 2015)	**10. Research Readiness**	The readiness of results to be applied in decision or management contexts. *See A-3 for results.*

2.3.3 Interviews

Following the documentary analysis, we recruited grant recipients (i.e. Principal Investigators and other funded project personnel listed on the front page of project reports) to participate in a telephone interview. These individuals were typically scientists or workers at the boundary of research and practice. Thirty-four grantees were interviewed, and each of them were asked to refer us to users engaged during their project(s) for follow-up interviews, yielding an additional 6 interviews for a total of 40. Interviewees collectively represented 42 distinct projects, as some were funded on multiple occasions. Between seven and nine projects per generation were represented for Generations 1-3 and 17 projects were represented in Generation 4. Additionally, two project team members also considered themselves users of previous NERRS sponsored research.

We applied a semi-structured format for these interviews (see A-2 for interview guide). Some questions focused on validating the attributes also examined through project report coding. Other questions focused on understanding more about project origins as well as its impact beyond the date of the final project report. The two interviewers regularly conferred and periodically conducted joint interviews to ensure consistency in approach. Interviews were recorded and transcripts produced through third-party transcription services. Additionally, interviewers logged interview contact reports immediately following each interview, where key themes relevant to research questions and other insights were documented. We coded interview transcripts using many of the same codes developed for the report coding.

2.3.4 Statistical Analysis

Selected coding from project report data (n=120) was analyzed in R. Coding groups related to research practice and use (Table 2-1) were read into R as ordinal or binary variables.

Using ordinal or logistic regressions, we tested the magnitude and significance of change between generations for each of the variables related to research practice. Additional analyses were performed by re-leveling generations so that models could be run with each generation as the reference level (see A-4). We also used logistic regressions to test the influence of multiple hypothesized drivers of the dependent variable Use (Table 2-2)

2.3.5 Study limitations

In using the NERRS experience as a natural experiment, several limitations arise. First, as previously mentioned, our coding structure is developed around high-inference themes, which necessarily demand higher levels of subjective interpretation by coders than other coding approaches. While such approach was warranted, given the need to systematically gather attributes of interest to this study that were oftentimes difficult to surface within project reports, our coding framework is less likely to be directly transferrable to studies of other programs. Second, in selecting codes that could be analyzed consistently across the study period, there were limitations to what kinds of themes, and what level of granularity within those themes, we could analyze. For example, we would have ideally considered a more nuanced typology within our coding for use, but implementing such a structure consistently across the full sample of project reports (which varied in terms of reporting style, depth and research topic) would have been very difficult to achieve. Finally, as this study presents a natural experiment, the relationship between funding, research practice, and use in each of the research and applied settings examined are undoubtedly influenced by myriad factors that are not systematically accounted for in this study. Furthermore, as pointed out on several occasions by some NERR staff, the study period may overlap with a period of change in research cultures occurring independently of changes in NERRS research funding.

2.4 ***Results***

2.4.1 Sponsor influence on research practice

Results from documentary analysis of final project reports shows significant change in how grant recipients oriented, designed, conducted, and disseminated their research. Attributes of research practice included Aims, Origin of Questions and Design, Relevance to Decision-Making or Management Context, Dissemination approaches, and Form and Intensity of Interaction with users (Figure 2-2 & Figure 2-3; see also A-1). Changes identified in these coding groups mostly correspond to the changing emphases of the program solicitation. For example, relative focus on New Science or Data versus New Technology mirror the shifting emphases on technology development (Figure 2-2a-b). Similarly, the program's increasing attention to management needs and user collaboration is reflected by an increase in users helping to shape research questions and design (i.e., co-design; Figure 2-2c-d). Over time, grantees also offered more specific descriptions of the context within and criteria by which users make decisions (Figure 2-2e-f). Moreover, subtler changes were observed with respect to Dissemination (2-2g-h), indicating the persistence of academic-style outputs even as more user engagement occurred.

Our analysis focused in particular on the nature of user involvement in the research projects. Figure 2-3 presents coding results for Interaction Intensity, adapting a typology of stakeholder engagement offered by Klenk and colleagues (2015). These results depict consistent movement toward more direct (i.e. working with users themselves versus intermediaries), intense (i.e. more frequent and collaborative), and conversant (i.e. more two-way communication) interaction with users. In each of the first three generations, more than half of projects exhibited no interaction with users; yet by the final generation, nearly all projects reported some form of interaction, and more than half demonstrated higher levels of interaction.

We analyzed ordinal and binary coded variables to generate odds ratios and other statistical values that portray the magnitude and significance of change between generations (Figure 2-3, and Tables A 2-5 in A-4). This analysis shows the largest shifts in research practice occurring in Generation 4, when the most intensive collaboration requirements were instituted. In the case of Interaction Intensity, the odds ratio of moving from a lower level of interaction to one level higher (e.g., from Linking to Match-making) is two in Generation 2, five in Generation 3, and 500 in Generation 4. Odds ratios and p-values for Generation 4 relative to Generations 2 and 3 are also large and statistically significant, further suggesting the marked difference in Generation 4. Additional statistics for these variables with all other generations as the reference level are reported in A-4.

Interviews with grantees provided additional depth and context to project reports and in some cases were able to characterize change in individual perspectives on research that they associate with participation in the funding program itself. Box 2 shows how the way researchers characterized their role in shaping research impact has evolved through time. Additionally, interviews with users referred to us by grantees, though too few in number to be representative of the program's multi-stage evolution, offer a helpful complementary viewpoint.

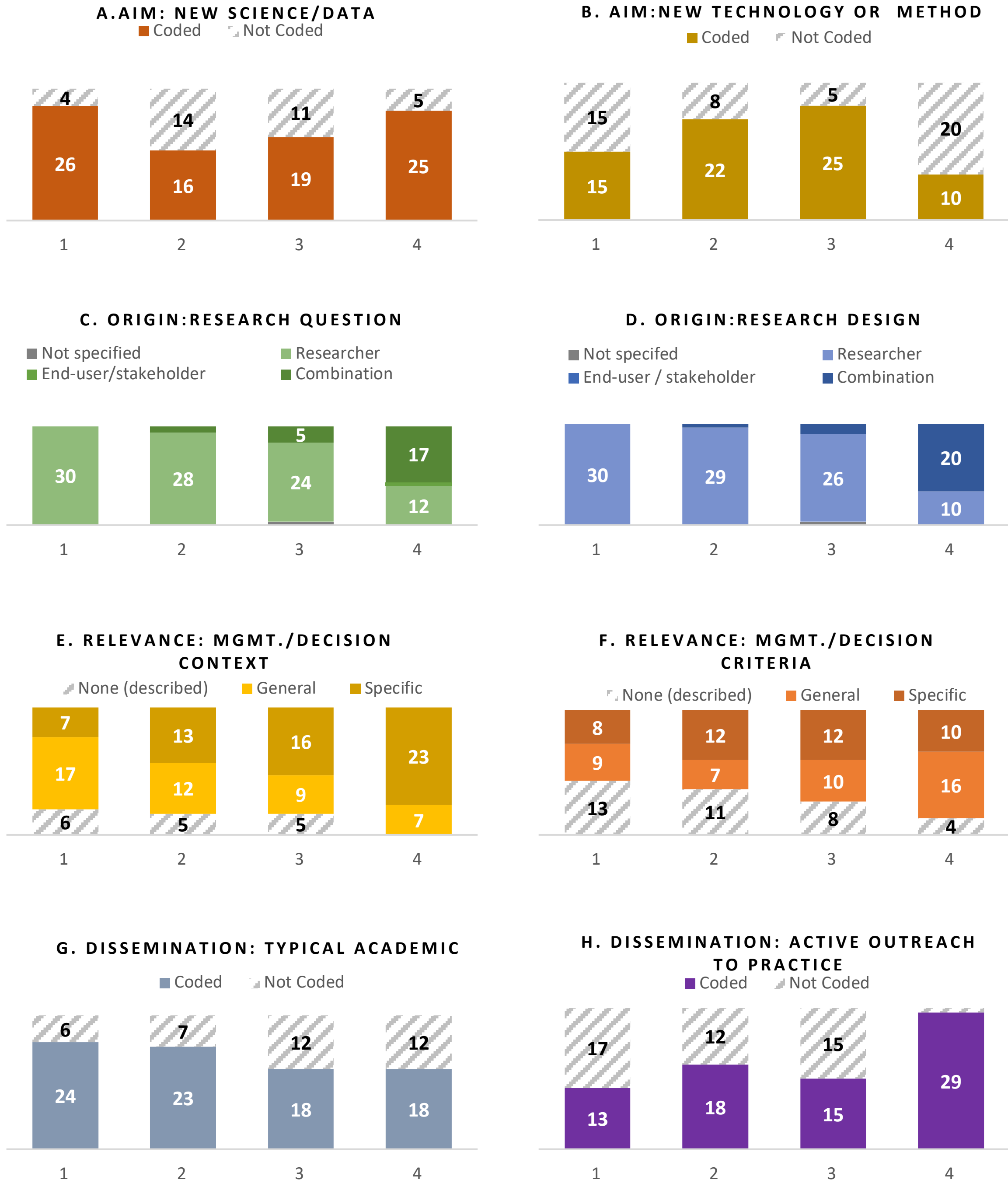


Figure 2-2. Results of documentary analysis of NERRS final project reports. Funding program generation labeled underneath bars. Thirty reports were randomly selected in each generation. Coding for "Aim" assessed the intended outcome of the research project: to generate new science/data (a), new technology (b), and/or other (see A-1). Coding for "Origin" assessed who helped shape research questions (c) and research design (d). Coding for "Relevance" assessed the degree of specificity (none, general, specific) provided by the project team regarding the management or decision-making context (e) or the criteria used for management or decision-making (f). Coding for "Dissemination" indicated whether evidence of typical academic dissemination (e.g., refereed publications, conference presentations) was present (g) and/or whether active outreach to practitioners (h) occurred. The 'not coded' theme is used for binary themes that are either present or absent. See A-3 for additional results.

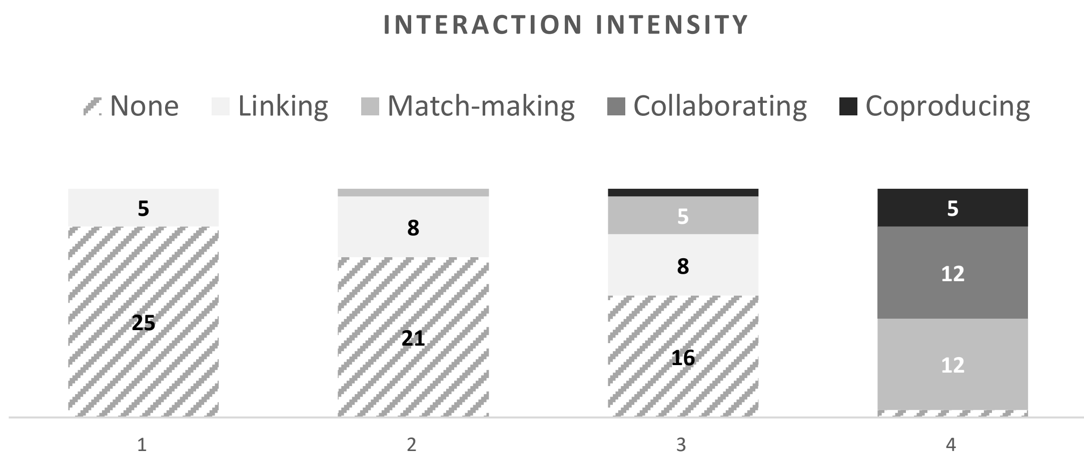


Figure 2-3. Results for coding on Interaction Intensity. Five levels of interaction were coded, ranging from "None" where no evidence for interaction with potential users was identified, to "Co-producing" where users either led or co-led the research project and engaged substantively throughout (coding scheme adapted from Klenk et al., 2015). Additional details on coding values and additional coding results and further analysis related to interaction provided in A-3 and A-4, respectively.

Grantees, most of whom would identify as researchers, were candid about their "*cravenly opportunistic*"—as one marine ecologist put it—approach to seeking funding from NERRS. In some cases, this level of entrepreneurship merely led to a self-selection process, where recipients chose to apply to a program when it was a good fit. For example, a geochemist from Generation 1 said *"[the program] had a problem that needed to be solved[…] and we had the right approach*," while another marine ecologist from Generation 4 said, "*[the program] was just a really good fit: it gave us sort of the natural…landscape in which to implement ..the framework of the project."* One particular recipient who managed both research and outreach components of three different projects funded in Generations 3 and 4 revealed how working to meet funder requirements did not forestall opportunity for a more authentic embrace of collaborative science eventually. At the start, they confessed to "*trying to get the right answer*" when writing their proposal, and at the outset having a "*not very sophisticated idea of how to bring in an end user*."

Yet, over time, this changed. In their words, "*We really got[...] inoculated with it in phase one and it was just such a successful model that we've continued*." As this grantee elaborated, lessons learned during earlier stages of the project helped guide their efforts toward more meaningful outcomes as they also doubled down on their commitment to a more collaborative style of research and refined their vision along the way for who their users were and how best to engage with them.

Those who were funded only once by NERRS provide a point-in-time perspective about how the funding program shaped their research design. As indicative of early-on expectations, a Generation 2 biologist said: *"I didn't have any intimate knowledge…of what the needs of the sites were. I was responding specifically to what was in the solicitation package."* Even without the benefit of comparison to other generations, statements by one-time recipients in Generation 4 reference the influence of the funder through comments such as, "*I don't think we would have done anything that ambitious nor that highly connected to the communities, nor that highly networked nationally"* and "*I liked the idea of being challenged to modify the project in response to the stakeholders*".

Box 2 Representative quotes by generation

Generation 1: "I feel like it's my responsibility to convey this information but it's their responsibility to either use it in a constructive way or ignore it."

Generation 2: "Applied research is no longer a derogatory term. Applied research requires that you go beyond a silo in which you were trained."

Generation 3: "It moves you from just a research mode to [...] thinking much more critically about factors of adoption and of use..."

Generation 4: "if you didn't have a collaborative outreach partner, you weren't going to get funded. That was clear from the get-go. I think it had a big influence on what we did and how we thought…"

Those funded by NERRS over multiple generations offer complementary and longitudinal perspectives. For example, a researcher funded on four occasions during

Generations 1, 2, and 3 reflected on his early work saying, "*I think that in general the work that I had done in the past would have been more successful if I had spent the time and effort on those important relationships and kept those people as an integral part of these projects."* A geospatial and data scientist funded on two different generations and involved with NERRS over the entire period said, *"[In the early days [...] you could fake [collaboration…] and you could get support. But as time went on, [the funder] became more and more attuned to importance of those aspects and I think became more and more cognizant of how the RFP structure itself could improve those outcomes."* In earlier generations, a team leader funded multiple times said that at first they "w*ere not in knowledge co-production mode when we were doing this work with the various entities. Even though we probably said something to that effect, I think it probably was not really true.*"

Although grantees seemed to understand and respond to the logic of interacting with potential users to increase the likelihood that their research was used, we also routinely found interviewees embracing the mode of knowledge co-production for more than one reason. Frequently, when responding to our question about what the most memorable aspect of the project was, interviewees would describe the experience of collaboration itself. Though the utilitarian merits of collaboration to increase project effectiveness and use of outputs were not neglected, a deeper, oftentimes personal, embrace of collaboration was evident. This interview excerpt exemplifies this blending of motivations:

> Interviewee: I really enjoyed working on this project. You know, perhaps more so than other projects that are strictly science focused. I really enjoy working with stakeholders and having that kind of involvement. So it was fun for me to do for sure.
>
> Interviewer: And anything in particular about why that's more enjoyable or meaningful?

> Interviewee: It just felt like it was more useful in the end. Our goal is always to publish papers and be part of the peer reviewed scientific literature. But those don't always translate to people on the ground making decisions. They're not going out to the scientific literature to ... It's a bit more complicated than they might want to try to read. So it was just rewarding in that aspect.

From interviews with users we gained new insights into some of the projects. From these. we identified two important themes, each of which could merit further exploration in subsequent studies of user experiences in collaborative science projcets. First, collaborative work has progressively become a part of their jobs, whether collaborating with other researchers or community stakeholders. One user referred to this as part a "*cultural shift in the way people work*." While some described this as just a more personally satisfying approach, there was a general recognition of its efficacy. For example, a user participant in a Generation 3 project simply stated with regard to the collaborative approach, "*I don't know how it would've gotten done otherwise.*" Second, users spoke about how different forms and intensities of collaboration are appropriate to meet different objectives. From one user engaged during a Generation 1 study: *"I'm not right there with [the researcher] standing in the water with him when he is doing the work."* In this person's view, such proximity is unnecessary except at particular stages. Another user engaged during Generation 4, emphasized the importance of enabling different individuals to engage at different levels of intensity and that different forms of collaboration may be necessary depending on the outcome. As he said, "*For a large manual like this, I think you've gotta have a big group."*

2.4.2 Influence of interaction with users on knowledge use

Our coding process identified where evidence of Use was presented, when it was not presented (i.e. Non-Use), and when there was no basis for a judgement either way (i.e. Indeterminate). In this process, we refrained from judging quality of Use but rather made a summary judgement of what grant recipients communicated. An example of reported Use (redacted to preserve anonymity) read like this: "*Our project has resulted in updates to [state agency guidance document]. [The state agency] updated the bioretention specification in the manual during the project.*" An example of definitive Non-Use read like this: "*Because the biosensor technology is not yet at the stage where it is useful for management applications, it has not been widely transmitted.*" An "Indeterminate" judgement was made when either use was anticipated at some future point in time, when no statements were made regarding any type of use, or when text in the report referring to use was too vague to support a judgement. In this screening, dissemination activities alone did not satisfy the threshold for Use. When evidence of use was identified, secondary codes distinguished the use type based upon on Pelz (1978): direct use for decision-making and management actions was coded as "Instrumental" and indirect use to inform priorities and increase general awareness of issues was coded as "Conceptual." We attempted to code for "Symbolic" use for when research was applied to justify pre-existing positions, but no evidence for that form of use was presented, reinforcing the challenge of operationalizing this typology.

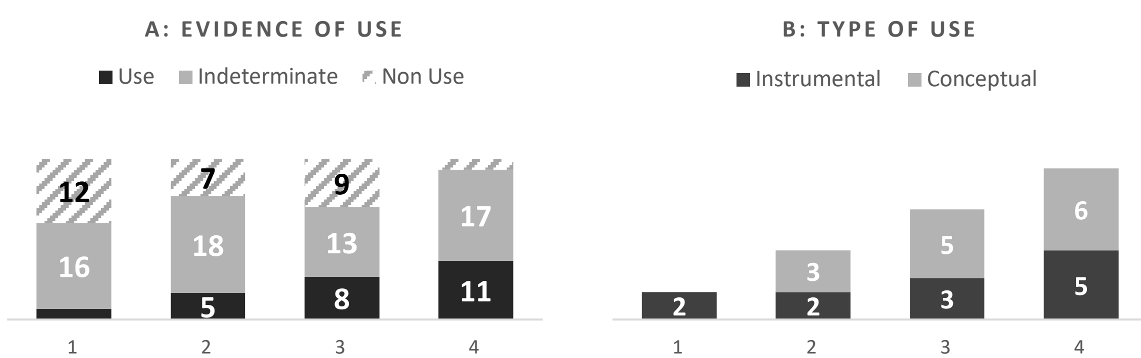


Figure 2-4. Coding results related to use. Panel A provides the first level of coding on use. In that coding, Indeterminate refers to when evidence of use was deemed insufficient or not present. Non-use was coded when specific evidence of non-use was provided in the project report. Panel B provides coding data on the type of use identified for those projects where evidence of use was coded.

Project report coding identified modest increases in evidence of research use, though this signal is likely dampened due to the nature of standard research reporting. Nevertheless, coding results for Use (Figure 2-4) show three meaningful trends. First, in each successive funding generation there is an increase in use as well as an overall decrease in Non-Use. Second, across all generations, the majority of projects provide no conclusive evidence for Use or Non-Use; that is, in most cases regardless of funding generation, demonstrable evidence for Use or Non-Use was not found in the final project report. This high proportion of Indeterminate codes maybe explained both by the timing of when project reports are completed (90 days following project completion) and by the lack of systematic and specific reporting on research use in the context of standard research reports. Third, except for the Generation 1, there is a relative balance between Conceptual and Instrumental use. The analysis of Use alongside attributes of research practice suggests that a stronger user-orientation of research is associated with greater Use (see Figure 2-5).

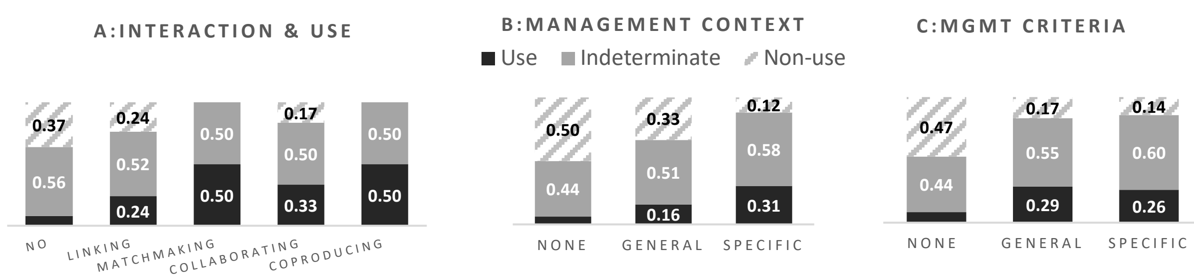


Figure 2-5. Cross tabulations for use and research attributes, including interaction intensity (a), management context (b), and management criteria (c).

To examine drivers of scientific knowledge use, we consolidated coding data for Use as a binary outcome variable ("Indeterminate" and "Non-Use" combined). Then, we ran a set of logistic regression models that tested the influence of year, generation, and other independent variables on Use (see Table 2-2). In Model 2, odds ratios suggest that evidence for use of sponsored research increased by almost a factor of three for Generation 2, by a factor of five for Generation 3, and a factor of eight for Generation 4. In the next sequence of models presented, Interaction Intensity emerges as a consistently significant determinant of Use.

Table 2-2 Logistic regression results for binary outcome variable "Use"

	Model 1		**Model 2**			**Model 3**		**Model 4**		**Model 5**	
	Coeff.	*z*	*Coeff.*	*OR (95%CI)*	*z*	*Coeff.*	*z*	*Coeff.*	*z*	*Coeff.*	*z*
Year	0.16	2.96***									
Funding generations											
Generation 2			1.03	2.80 (0.55, 20.78)	1.17	0.87	0.98				
Generation 3			1.63	5.09 (1.14, 35.05)	1.94*	1.10	1.25				
Generation 4			2.09	8.12 (1.91, 56.34)	2.54**	-0.00	-0.00				
Research practice variables											
Aim: New Science/Data										-0.60	-1.00
Aim: New Technology										-0.15	-0.28
Origin: Research Question										-0.08	-0.21
Origin: Research Design										-0.46	-1.22
Relevance: Context								0.19	0.38	0.24	0.46
Relevance: Criteria								0.30	0.79	0.31	0.77
Dissemination: Academic										-0.74	-1.38
Dissemination: Practice										0.91	1.75*
Interaction: Intensity			p < 0.1 - *, <.05 - **, <.01 ***			0.83	2.63***	0.58	2.88***	0.74	2.36**
Model diagnostics											
df	119 (118)		119 (116)			119 (115)		119 (116)		119 (112)	
AIC	119.6		123.95			118.1		117.94		120.5	
Res.Dev.	115.6		115.65			108.1		109.84		104.5	

Since the interviews took place several years or more after the conclusion of the project and included more targeted questions regarding use than prompted by project reports, they add richness to the data from project report coding. Thus, we also coded interviews for Use similarly to project reports. The interviewees addressed use in 49 projects. Out of those, 17 interviewees provided comments regarding Use that resulted in a lower level appraisal than gathered from project reports, (i.e., from Use to Indeterminate, or Indeterminate to Non-use), 15 interviewees provided comments that resulted in a higher-level appraisal (i.e., from Non-use to Indeterminate, or Indeterminate to Use). No change occurred for the remaining 17 projects. The results from the interview coding provide a similar depiction to the report coding, though with less change in any of the Use categories from Generations 1-3 and a lower proportion of projects coded as Indeterminate. This is perhaps because direct questions during the interview on use as well as the additional time elapsed since final report writing enabled respondents the ability to offer more detail than before.

Grant recipients and users spoke to the importance of interactions with each other as influential factors that shaped the usability of end results, reinforcing the statistical analysis of project report data, though with greater nuance. In trying to attribute user participation to the success of the project, one grantee gave two explanations: "*Part of it was being involved in a process in the project that had a forward-looking, proactive, positive appeal, organizational culture… [The other part was], they said they needed these things and they got them.*" Others highlighted how the "*iterative nature provides much greater confidence [for users], in that they were involved somewhat in terms of the design of the tool itself.*" Additionally, user participation was also linked with credibility as represented in this quote:

> *I think that if we had just done this in a closed room with a bunch of engineers or if we sat around with [organization name] and did something like this, I think nobody would've paid attention, but having all these different people involved and able to provide their experience and perspective really lent that credibility that was absolutely necessary.*

Despite the centrality of interaction to many grantee's recollection of their project and how they attributed success in generating usable outcomes, they pointed to other factors working in conjunction with interaction. These included the motivation and readiness of users, the demonstrable feasibility of a particular technology or method, and social and political factors that shaped the broader context for use.

2.5 ***Discussion***

The two most compelling findings from the data analyzed here are that funding agencies have significant influence on research practice and that there is a relationship between the intensity of the interaction between researchers and practitioners and use. First, in contrast with studies that pointed out the limitations or risks of funders' interventions (De Rijcke, Wouters, Rushforth, Franssen, & Hammarfelt, 2016; Holbrook, 2012; Lövbrand, 2011; Reale & Zinilli, 2017), our evidence suggests a critically important role for funders in driving meaningful changes to research practice. Second, going beyond qualitative case studies, this research provides a larger and more systematically analyzed dataset that suggests more interaction between researchers and practitioners increases use, further supporting earlier scholarship in this area (Dilling & Lemos, 2011; Fujitani et al., 2017).

When considering approaches to science funding program management, this evidence helps compare alternative, more impact-oriented funding models with conventional, more linear approaches. As described earlier, NERRS funding was initially organized similarly to most U.S. basic research programs. As described by one of its longstanding program officers, NERRS began with the assumption that "*the information, knowledge, and technology resulting from the funded research will make their way into actual management and use through the traditional means of conveying scientific information*." This approach, still commonplace in research funding today, is often depicted as a linear, one-way pipeline of resources and knowledge from funding to research to end-use (see Figure 2-6a). But the progression of NERRS over time—represented by both the evolving spirit and letter of the program design—gathered users, researchers, and the sponsor into an arrangement where two-way interaction would occur more actively between the three groups and lead to changes within each. Currently, for example, the program operates through a series of multi-way interactions with collaborative research continuing between users and researchers. Program managers also provide ongoing feedback, support, and check-ins between program managers and researchers. Finally, program manager administer pre- and post- questionnaires with users to more directly assess use and other outcomes (Trueblood et al., 2019; see Figure 2-6b).

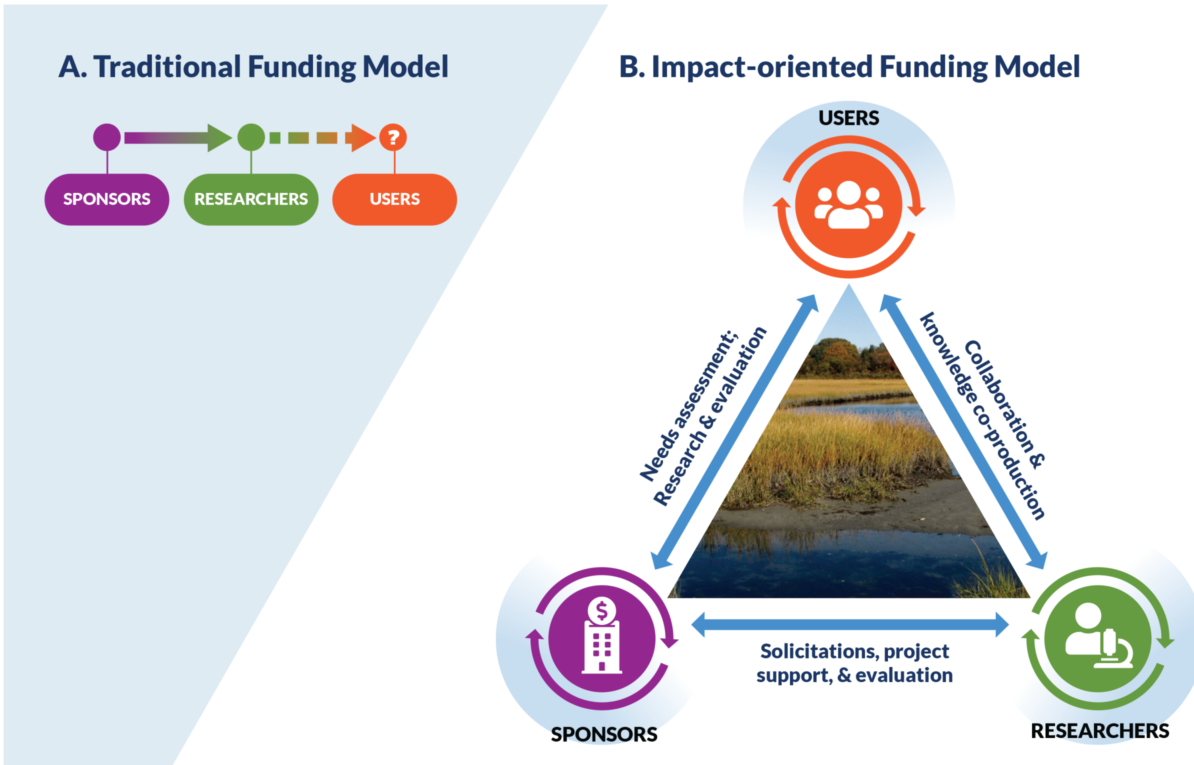


Figure 2-6. Two different models to structure funding for research. In a), the traditional funding model, research sponsors provide directives and financial resources to selected researchers, who are afforded general autonomy to pursue proposed research. Connections between the researchers and users are tenuous, and it frequently remains unclear whether use occurs. In b), the impact-oriented funding model—which the NERRS example is evolving towards—sponsors, researchers, and users all maintain active lines of two-way communication and interaction that can inform research program agendas, research projects aims and methods, and well as new insights for problem solving in the contexts for application.

Additionally, similarly to other scholars, we caution against wholesale transition to funding models that are guided by utilitarian principles alone (Flexner, 2017). Ultimately, our data shows that not all research need to be conducted in high-intensity interaction modes in order to be utilized and that not all co-produced science leads to use (Lemos et al., 2018). In this sense, this study also contributes to current thread of discussion in the literature about how much interaction between research and practice is optimal (Lemos et al., 2019; Trainor et al., 2016).

Still more research is needed to understand how different forms and intensities of interaction influences use in different settings, and this research would benefit from incorporating questions about how different mediums for interaction (e.g. virtual, asynchronous) help or hinder the co-production process and achievement of intended outcomes. Our examination of NERRS—and hopefully future studies of funding programs like it—could be fertile ground for the examination of these issues in different settings. Furthermore, a methodological finding of this study is how labor-intensive it can be to interpret drivers and outcomes from standard research reports – hence, we encourage funders to modify project reporting structures if the goal is to foster use.

2.6 *Conclusion*

The desire to make science usable for solving societal problems is challenging the traditional conceptualization of science and society as separated realms. Guided by different motivations, global change and sustainability scientists are in many cases departing from conventional approaches by embracing co-production and looking to practical problems and expertise from non-scientists to guide and apply their science. Given what we already know about the potential benefits of co-production, this change may lead to significant increase in the societal impact of science. At the same time, this study also raises important, and still unresolved, issues surrounding the grand challenge we introduce at the outset: how can science best help society manage risk and make progress toward sustainability in the midst of global environmental change? At its core, this question begs critical examination as to whether scientific structures can (or should) change to be more collaborative, inclusive, and de-siloed; and if such a move to more interactive and engaged research practice will yield meaningful gains in the use of scientific knowledge. Understanding in greater detail what particular benefits arise and the pathway to achieving them at scale amid accelerating environmental challenges often remain unclear.

This study makes progress on this understanding by providing new empirical evidence for how funders can catalyze more collaborative research and help increase its use in support of environmental sustainability goals. Specifically, we examined a coastal and environmental research program that, over 16 years, transformed from a traditional funding model to embrace, and eventually incentivize, more engaged research. We found these changes influence research practice beyond perfunctory compliance and that a movement toward co-production supports increased utilization. These findings provide stronger validation—but also nuance and some caveats—to the conclusions of prior literature on co-production. Indeed, we still need to be cautious when designing research funding programs to ensure that research-practice relationships proceed equitably, effectively, and efficiently. Ongoing research into how forms and intensities of interaction can be optimized and how different approaches are deemed satisfying, or equitable, by participants could help contribute to improve what works best. Research that ties together cohorts of funders pursuing similar approaches simultaneously would further strengthen the evidence base across contexts and foster learning more relevant to guiding program intervention. In this, we see great opportunity for funders to work with science policy and evaluation researchers to re-imagine project reporting approaches to reduce grantee burden while also accelerating learning and safeguarding against "lip service" or exploitative arrangements with stakeholders. In fact, such collaboration could be another potentially fruitful form of knowledge co-production, helping to make knowledge about co-production, itself, more usable. These results are not intended to suggest conventional forms of research funding and practice are necessarily unsuitable for making progress in some areas of science intended to help to manage risk from global change or to enhance sustainability. But we do see immense potential for emerging and alternative ways of doing science to help society meet the challenges of solving environmental problems. Indeed, through this research we see evidence of cultural shifts underway that embrace co-production for both its practical and intrinsic benefits. We hope that this research will help to guide researchers, users, and funders alike.

Chapter 3. Understanding Knowledge Use for Sustainability

This chapter is based on a manuscript in preparation for submission to *Environmental Science & Policy* as: Arnott, J. C. & Lemos, M. C. Understanding knowledge use for sustainability.

3.1 *Introduction*

Generating usable science for sustainability has the potential to transform both science and society, but efficiently harnessing this power for good requires a deeper understanding about knowledge use. As societies around the world have amplified their commitment to tackle ambitious sustainability goals (Lubchenco, Barner, Cerny-Chipman, & Reimer, 2015; United Nations, 2015), appreciation has also grown for the complexities surrounding the relationship between science and action. Large amounts of scientific knowledge sit on the shelf or become utilized in very subtle, unexpected, or even subversive ways because we still do not fully understand the mix of cognitive and organizational factors that influence information use (Feldman, 1989; Landry, Amara, & Lamari, 2001; Langer, Tripney, & Gough, 2016; Weiss & Bucuvalas, 1980). Moreover, even the best designed attempts to link science with sustainability may be fraught with issues of unintended outcomes, equity, legitimacy, and politics (Klenk & Meehan, 2017; Lövbrand, 2011; Turnhout, Dewulf, & Hulme, 2015).

Already, a substantial literature has characterized and explained different forms of research utilization (e.g., Caplan, 1979; Knott and Wildavsky, 1981; Landry et al., 2003, 2001; Pelz, 1978; Weiss and Bucuvalas, 1980). Yet, the study of how scientific knowledge links with action in the environment and sustainability domains focuses less on defining or evaluating use and more on unpacking the kinds of strategies that may lead to its achievement, however defined or understood (Clark et al., 2016; Kirchhoff et al., 2013; Reed, 2008). For example, a large amount of attention has been paid to the role of collaborative, societally-engaged, and challenge-driven approaches to science that contrast with more traditional, quasi-autonomous, and discovery-driven approaches (Cash et al., 2003; Dilling & Lemos, 2011; Fujitani et al., 2017; Funtowicz & Ravetz, 1992; Gibbons et al., 1994; Mach et al., in review). Within this context, meaningful interaction between researchers and users, or scientific knowledge co-production, has become a deliberate and increasingly adopted method for producing science for use in decision-making (Bremer & Meisch, 2017; Lemos & Morehouse, 2005; Meadow et al., 2015; Vano et al., 2017).

Yet, testing strategies such as co-production for producing usable knowledge across contexts, and understanding the different types of conditions in which knowledge uptake occurs, remains difficult. On the one hand, scholarship on research utilization has suggested these challenges are largely due to data limitations and the difficulty in characterizing the variables and mechanisms necessary to study knowledge use (Landry et al., 2003; Larsen, 1981; Wall et al., 2017). However, on the other hand, because publicly funded projects stem from relatively autonomous research cultures and typically engage actors within notoriously decentralized academic institutions (Holbrook, 2010), these projects can be characterized as microcosms of the 'organized anarchies' concept that Cohen, March, and Olsen (1972) coined to describe academic organizations in general. In this view, preferences on outcomes for research projects are as fluid as the methods employed to achieve them and the diversity of participants engaged in their execution. Indeed, we argue that their notion of a "garbage can" model of decision-making within organized anarchies is fitting to describe the messy and difficult-to-predict way many research-practice partnerships are formed and proceed into implementation. And despite a deliberate intent to produce usable knowledge, these processes are neither an idealized linear flow of information production-to-use, nor are they an idealized adaptive cycle of planning, information gathering, experimentation, monitoring, and re-evaluation. Instead, the processes, decisions, and outcomes mobilized through grant-funded collaborative research projects can be difficult to discern, describe, and evaluate, particularly from the standpoint of their non-economic societal benefits (Bozeman & Youtie, 2017; Wall et al., 2017).

In this chapter we examine the intentional process of producing usable sustainability science and how it influences knowledge use. We explore how researchers themselves grapple with the challenges of defining, characterizing, and promoting use. We ask: to what extent are these challenges alleviated within the context of more deliberate approaches to producing usable science? Does the deliberate design of iterative collaboration between scientists and users yield what funders and scientists expect in terms of use? And if not, what are the implications of this disconnect between expectations and actual outcomes?

Through systematic analysis of interviews (n=32) with grantees funded through an applied coastal research program from 1998-2014, we report: a) their perspectives on the kinds of uses that may happen, who the users are, and how use is tracked; and b) what factors contribute to use and non-use, and what beneficial outcomes, intended or otherwise, result. As an applied coastal research program that increasingly required its grantees to collaborate with resource managers, NERRS serves as testbed for understanding the deliberate effort to co-produce knowledge. Our analysis focuses on researcher perspectives from within this context to understand the connection between knowledge production and use and how best to institutionalize and incentivize co-production as a means to increasing the usability of sustainability science.

In the following section (3.2), we review relevant literature from studies of sustainability science use, decision-making, policy-making, public administration, and of the scientific process itself. In Section 3.3 we describe the setting from which the projects and interviews we draw upon in this study emerge and detail our approach for data collection and analysis. The results from this analysis are presented in Section 3.4 followed by discussion in Section 3.5. In Section 3.6, we briefly conclude.

3.2 *Background*

What makes scientific knowledge actionable is both a basic and applied social science question (Lemos et al., 2018; Weiss & Bucuvalas, 1980). Yet, when it comes to building fundamental understanding about usable science, scholars of science use have been hard pressed to produce an evidence base relevant to those funding, making, and using actionable scientific knowledge. Research into the use of science in decision-making seems irretrievably disconnected from the increasing interest from those investing their money or time into producing knowledge that gets used to inform meaningful sustainability action. There has also been a separation between this scholarship and the underlying methods and definitions required to adequately study or evaluate the outcomes of different strategies to increase the impact of science. For example, in their study of mental health research utilization, Weiss and Bucuvalas explain how “unclear” and “foggy” definitions confound the study of use. But their examination of different types of utilization largely focuses on the end of the process, that is, the role of the decision-maker rather than examining the process of research production or interactions between the two (1980, p. 15). In contrast, more recent work on co-production of climate and environmental science highlights the influential role of deliberate science-practice interactions and offers typologies of engagement and interaction (Meadow et al. 2015, Klenk et al. 2015). Yet this work does not relate how different components of processes could be expected to yield different forms of use, let alone explain how to measure any form of use. It is this gap between process and outcome that we explore further in this section and, later, with new data and analysis.

3.2.1 The deliberate production of usable sustainability science

Scholarship on knowledge use has advanced ideas for how connections between science and decision-making on complex, value-laden topics like sustainability could be strengthened through alternative modes of research production (Funtowicz & Ravetz, 1992; Kirchhoff et al., 2013; Lemos & Morehouse, 2005). As a result, the customary supply-driven, linear model for knowledge *transfer*—where scientists work to produce more knowledge and disseminate it through unidirectional means like publications—has been met by the emergence of alternative approaches that consciously seek to understand the knowledge needs of users through processes of knowledge *exchange* (Cash et al., 2006; Sarewitz & Pielke, 2007). In this more engaged and interactive approach, researchers deliberately work with potential users to co-produce knowledge with the expectation of yielding more relevant, credible, and ultimately more usable knowledge for decision-making (Lemos & Morehouse, 2005; Meadow et al., 2015).

A growing number of studies have aimed to empirically test more interactive research approaches in various areas of sustainability practice (e.g., Chapter 2; Cash et al., 2003; Dilling & Lemos, 2011; Fujitani et al., 2017). Their results support the idea that more collaborative scientific practices such as co-production can generate greater societal benefits by working *with* and *for* society, rather than talking *at* society or operating at a distance *from* society (Fujitani et al., 2017). But while knowledge use is a motivating goal in this work, the concept of use itself is either measured coarsely as a binary variable (i.e. use or non-use) (e.g., Dilling & Lemos, 2011; Chapter 2) or is represented via proxies (e.g., comprehension, information retention, perceived credibility) (Cash et al., 2003; Fujitani et al., 2017; Lemos et al., 2019). Moreover, successful use also occurs outside of and beyond science-practice interactions, and more interaction does not always lead to use (Lemos et al., 2019; Porter and Dessai, 2017; Chapter 2).

Some scholars of knowledge use also point out that aspirations and institutional incentives to co-produce knowledge may not sufficiently account for equity or incorporate other forms of knowledge (Mach et al., in review). Another concern arises over how participants from the 'real world', such as practitioners, can get fatigued from rising pressure to collaborate with scientists, especially when they may not reap the same rewards from engagement as their researcher counterparts (Klenk et al., 2015; Newton & Elliott, 2016). Furthermore, from the perspective of practice, scientific knowledge is usually not the only, or the most limiting, barrier to progress on sustainability action (Nordgren, Stults, & Meerow, 2016). Thus, despite reasons for confidence in more deliberate forms of engaged research to achieve desirable outcomes, more insight is needed to attend to many outstanding issues that could affect the desirability or feasibility of escalating the amount of interaction between research and practice.

3.2.2 Unpacking knowledge use

Intuitively, usable science would seem to be the kind of systematic knowledge that can be *used* to directly and immediately inform a decision or action. But over time, definitions of the use of scientific knowledge—in its various forms (e.g., data, information, technologies)—have evolved. In the study of technology adoption, for example, scholars once constructed use as a simple binary variable of use and non-use (Ryan & Gross, 1943). Subsequent work in the field of policy sciences, defined direct forms of use as *instrumental* use, but also considered how knowledge can be employed to inform background understanding on a topic (i.e. conceptual use) or applied in more strategic ways to justify already established commitments (i.e. symbolic use)

(Pelz, 1978). Going further, use has been described based on the different ways uptake of knowledge happens at different stages of the decision- and policy-making processes (e.g., Knott & Wildavsky, 1981). Figure 3-1 illustrates these different ways of describing use.

Thinking more critically about what knowledge use actually means is relevant because attention to closing the science-to-action gap in the environment and sustainability fields has focused less on defining use and more on strategies to overcoming barriers to its achievement, such as through deliberate knowledge co-production (Kirchhoff et al., 2013; McNie, 2007). Yet, inquiry into research utilization has consistently cited unresolved barriers to studying use, which necessarily limit understanding its determinants and the efficacy of strategies to overcoming its obstacles. For example, Landry et al. (2003) itemized these methodological barriers as a four-fold challenge of:

1) identifying the study population (i.e. users)

2) specifying dependent variable(s) (i.e. use)

3) specifying independent variables

4) getting would-be users to recall or attribute use

Limitations in our ability to characterize uses, users, and determinants of usable knowledge hinder more systematic understanding of the extent to which, how, and why research is utilized (or not). Furthermore, from the standpoint of sustainability science, and our understanding of information use more generally, little is known about what positive broader outcomes can be expected from more usable knowledge, or about the unintended consequences of too pragmatic a focus on science usability relative to the intrinsic value of knowledge creation.

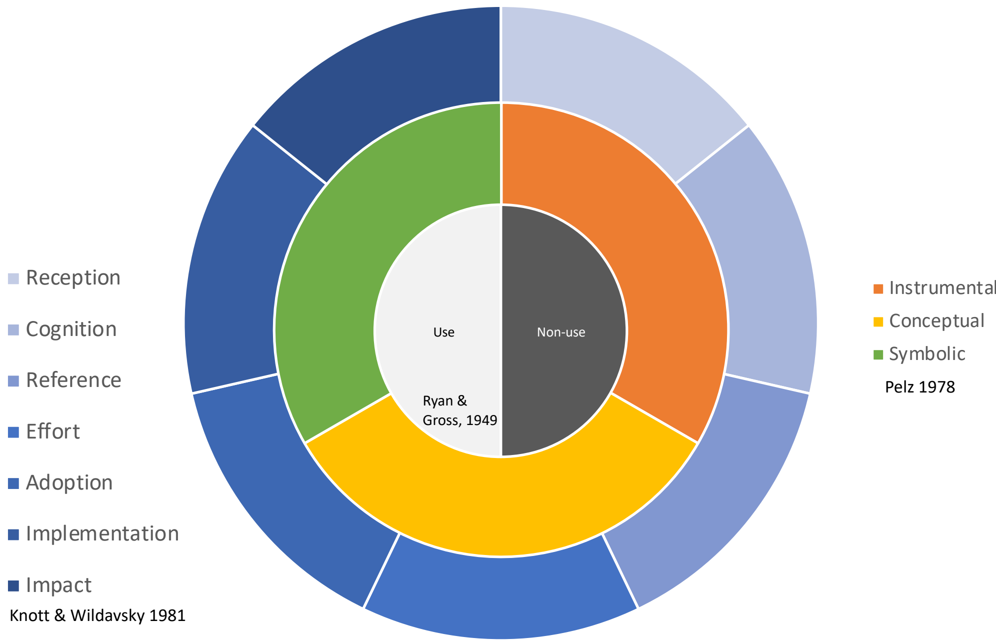


Figure 3-1. Three different typologies of use. In general, there has been a progression over time toward more multi-faceted conceptualization of use as depicted in this 'kaleidoscope' of use types. Knott and Wildavsky 1981 outline 6 types of use: a) Transmission: research results were transmitted to the practitioners or professionals contacted; b) Cognition: Research reports/findings were read and understood by the practitioners concerned; c) Reference: Research results were cited as a reference in the reports, studies, and strategies of actions elaborated by practitioners and professionals; d) Effort: Efforts were made to adopt the results by practitioners and professionals; e) Influence: Results influenced choice and decision of practitioners and professionals; f) Application/Impact: Research results gave rise to applications and extension by the practitioners and professionals concerned.

Limitations to the characterization use may affect our ability to attend to frequently cited barriers. For example, imprecise accounting for what use means makes it more difficult to compile robust knowledge about when and how different types of barriers are overcome. Barriers reported in the literature mainly relate to characteristics of the knowledge itself, such as the extent to which users perceive knowledge as relevant, timely, accessible, comprehensible, and (politically) palatable (Lemos et al., 2019; Pulwarty & Redmond, 1997; Weiss & Bucuvalas, 1980). Research focusing on barriers to use of science finds that new information may be pursued by decision-makers as a matter of course but without intention to change decision-making or merely as a tactic to delay action (Feldman & March, 1981; Weiss, 1979). Other times, scientific information may be presented too late in relation to relevant decision timelines or may not fit well into pre-established decision-making criteria or calendars (Moss, 2015; Ray & Webb, 2016). The conditions for use are not static either. Decision-makers, at different moments and across different contexts, may rely upon different "logics" for decision-making: sometimes decisions are taken based on standard procedures (i.e., what is 'appropriate'), other times based on what is estimated to lead to a particular outcome (i.e., what is 'consequential'), and still other times guided by the decision-maker's own efforts to make sense of the world (i.e., what is 'meaningful') (Dewulf, Klenk, Wyborn, Fieseler, & Lemos, in review). Across this complex environment, a variety of strategies to knowledge production will likely be necessary, yet advancing understanding of what works and why will require more systematic means of analysis to more effectively connect between process and outcome.

3.3 *Methods*

To understand how assumptions about use are formed in the context of the intentional effort to produce usable science, we focus on applied science projects funded by the National Estuarine Research Reserve System (NERRS), a program of the U.S. National Oceanic and Atmospheric Administration. While much is known about NERRS's nature and culture of collaboration between researchers and coastal managers, (Chapter 2; Matso, 2012a, 2012b; Matso & Becker, 2013, 2014; Riley et al., 2011; Trueblood et al., 2019) less research has focused on the outcomes of the program in terms of knowledge use. Although the overall goal of the program to produce usable science and technology for coastal and estuarine management has stayed constant over the study period, 1998-2014, program requirements changed every 3-5 years to require progressively more interaction between research and practice. The result has been the evolution to a fully-fledged program for funding co-produced sustainability science.

Table 3-1 Projects represented by generation

Generation	Number of Projects
I	5
II	7
III	8
IV	16

This study builds upon the database presented in the preceding chapter, for which we selected a random sample of 120 projects funded during this period for documentary analysis of final project reports and follow-up interviews with grantees (n=32; average interview length was 41 minutes, with a range between 13 and 87 minutes). All grantees named in selected final project reports were invited to interview. Because some grantees were funded more than once, these interviewees spoke in detail to 36 distinct projects. As outlined in Chapter 2, the evolution of the program is represented as a series of four distinctive generations, each of which was purposively redesigned by program managers to increase the uptake of knowledge into practice by coastal and estuarine management (see Figure 2-1). Although we invited grantees from all selected projects to interview, more grantees were successfully recruited from later generations (see Table 3-1).

Figure 3-2. Guiding questions for analysis of interview transcripts

These interviews were conducted using a semi-structured interview protocol (see A-2). Interviews were audio recorded and transcripts were produced through a third-party transcription service (rev.com; scribie.com). In the interviews, we asked respondents to characterize whether and how the results from their projects were utilized or had an impact in practice. We also invited respondents to reflect about how collaboration within the project shaped the outcomes and uses of the research. Although our key informant responses represent just one perspective in the multi-actor process of co-production, they are important because these individuals are the direct implementers of programs that specifically seek, through their funding requirements, to increase the use of sustainability knowledge.

Table 3-2 Selected coding attributes

User - Sectoral Specificity	User – Geographic Specificity	Use - Ryan and Gross 1943	Use – Pelz 1978	Use - Knott & Wildavsky 1981
a. General (public, people, etc) b. Broadly defined stakeholders, resource managers, practitioners, or decision-makers c. Multiple specific stakeholders, resource managers, practitioners, or decision-makers (3+ specific sectors) d. Stakeholders, resource managers, practitioners, or decision-makers (2-3 sectors) e. One specific end-user; one-specified context	a. Community b. Community - Regional c. Regional d. Regional - State e. State f. State- National g. National	a. Not used b. Indeterminate c. Used	a. Not used b. Indeterminate c. Conceptual d. Instrumental e. Symbolic	a. Not used b. Indeterminate d. Reception c. Cognition e. Reference f. Effort g. Adoption h. Implementation i. Impact

We coded the interviews to identify responses relevant to the framing of our study. Our coding is based on five themes identified in the literature as obstacles to advancing the study of knowledge use (e.g., Landry et al. 2003; see Figure 3-2). Our coding assessed how interviewees identified users and uses and how they tracked, attributed, and reported outcomes associated with use. We then created a table of anonymized descriptions of users and applied taxonomies to each user characterization for both sectoral and geographic placement (Table 3-2). We also coded for characterization of use, using three different typologies based upon those shown in Figure 3-1.

Despite the unique opportunity to explore the link between research practice and outcome afforded by this dataset, there are several limitations to this methodological approach. First, the design of the interview protocol and the dataset were not intended to be a formal program evaluation. While we included many probing questions during our interview, our aim was less about getting to the bottom of what actually occurred and more about understanding how actors in the process of co-production make sense of the connection between process and outcome. Second, our coding approach relies heavily on high-inference coding that was performed by a single coder. Thus, measurements of intercoder reliability are moot and, given the nature of the themes coded for, would likely be inappropriate. Finally, as suggested by Table 3-1, the interviews analyzed in this study take place over a broad time period, with different research topics and research styles. We were not able to evenly recruit interviewees across this time period or gain sufficient data from earlier generations, which prevents comparison between funding periods within the larger period of this study design.

3.4 ***Results***

Our interview data reveals researchers funded to produce usable knowledge characterize fundamental aspects of knowledge use in wide ranging, tentative, and often imprecise ways. As explored in further depth in the following subsections, these perspectives suggest that efforts to incentivize the production of usable knowledge through funding program design do not necessarily yield a well-ordered recounting of who users are and what kinds of uses occur. Instead, grantee interviews represent a more scattershot approach to describing these elements as well as attribution, tracking, and other outcomes of interaction. These grantee recollections reveal the highly emergent, unpredictable, and difficult steps that may be needed in order to articulate how deliberate co-production yields usable knowledge.

3.4.1 Who are the users?

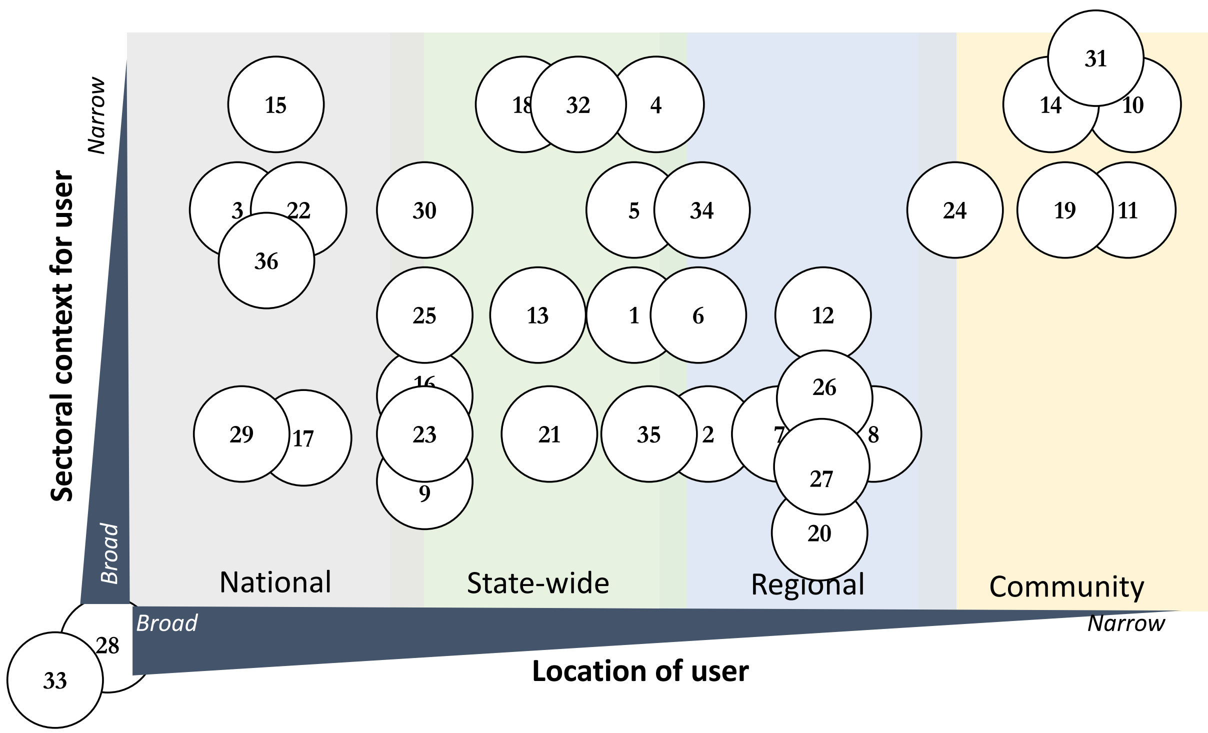


Figure 3-3. Qualitative scatter plot of the coding results for users. Each bubble represents a particular project with indexing corresponding with projects referenced elsewhere in the chapter. Overlapping bubbles represent projects with user characteristics that were coded to the identical sectoral and geographic combination but slightly moved for visibility. Projects 33 and 28 are outliers in the sense that no users (or uses) were identified by interviewees representing those projects.

Because NERRS required researchers to develop a close relationship with the estuarine reserves or other coastal partners, a relatively tightknit community of researchers developed. Notwithstanding, project teams pursued applications with users at varying geographic scales (ranging from a single community or organization, to the entire nation) and targeted user groups across multiple sectors and organizational types. Figure 3-3 provides a qualitative scatter plot of the different combinations of sectoral and geographic user contexts pursued by project teams based on our coding structure provided in Table 3-2. Each bubble represents a single project with a notation that corresponds to more descriptive detail about the users for each provided in Table 3-3.

Table 3-3 Reported end users for each project discussed in interviews

1	Regional planning commission, local NERR, state environmental quality regulators	**19**	Local public works and flood management staff, consultant hired by town, local reserve
2	Engineers, landscape architects, state and federal regulators.	**20**	Homeowners, engineers, business owners, towns/counties, local reserve, and the general public
3	Monitoring equipment company, NERRS	**21**	State water board and env. quality commissions and associated stakeholder committees
4	State regulators of erosion control structures	**22**	Federal mission science agencies
5	State Soil & Water Conservation Districts, a county engineer office	**23**	Federal and state governments devising strategies to make water quality standards; farmers (the regulated community) using technology to meet standards
6	Real estate developers, marine contractors, homeowners, state coastal management, state coastal commission	**24**	County and municipalities, soil and water conservation
7	Multi-stakeholder conservation groups, local reserve	**25**	Regional NERRs, local fishery managers
8	Engineers, city planners, counties, municipalities and private sector	**26**	Regional conservation groups, resource management entities
9	Federal regulators, local NERR, local business, State archives	**27**	Broad regional interests
10	Reserve Coastal Training Program	**28**	*None mentioned*
11	Watershed protection; Town	**29**	"Managers, for example"
12	Local watershed association, towns with and without wastewater treatment facilities	**30**	Federal and private entities responsible for cleanup
13	State natural resource management, soil & water conservation districts, a watershed partnership, local reserve; Reserve Coastal Training Program, engineer consulting firms	**31**	Local reserve
14	Local coastal park	**32**	Coastal resource managers that permit shoreline and bulkhead work
15	Federal environmental quality scientist	**33**	*None mentioned*
16	Coastal communities in the Northeast and elsewhere	**34**	Resource managers working with shellfish; shellfisherman
17	Federal environmental quality "folks", private sector, consulting companies	**35**	Restoration practitioner, wetlands manager, state agencies, land management, Reserve
18	The leader of the research project who became a state fisheries manager	**36**	Licensing agencies, environmental management companies

We also found the project team members' description of users of their research is generally characterized by uncertainty and improvisation, fluidity, and a tendency toward breadth in working to accommodate many types of users during their project (further described below). Often respondents had difficulty specifying user groups with confidence or precision. Additionally, who the users were changed over the course of the project and beyond, and we observed an inclination of grantees to be inclusive of many different types of potential users.

Uncertainty: respondents were both uncertain in stating who the actual users of their work might be and at times appeared to improvise or reflect on the spot who were their intended users. For example, a collaboration lead[1] for a project we interviewed quoted a scientist colleague's frustration with identifying users saying, "***You know, I talk about 'managers' all the time when I write my proposals, […] Actually [I] don't know who these people are. Who are they?***" But more frequently, the uncertainty was subtler, expressed in terms of thinking aloud during the context of the interview about who users were versus anonymous stakeholders more generally. For example, when pressed to clarify a point about users during a train of thought listing two different possible user options, one interviewee surmised, ***"I don't know, I would say both."***

Breadth: respondents also characterized users as any number of people and entities that express an interest in the topical area of research. This observation is typified by the comment, "***I mean when I say end users, I mean they're genuinely interested and they want to do similar things in their communities.***" Striking an inclusive tone seemed natural in most of the contexts for work described by grantees, particularly given the interconnectedness of the issues they were

[1] During later years of program design, the funder required a collaboration expert to serve as a Co-I or PI on the grant.

targeting. Thus, the breadth of selection of actors as characterized by this grantee seems wholly appropriate:

> *We had the research community within remote sensing joining effort with the resource managers who were managing the health of the shellfish, with those resource managers that were managing the health from a public health perspective. And, we had the shellfishermen themselves that were interested in this! So, we were very much a motley crew of folks that were out and about, all engaged in these efforts.*

Notwithstanding the exuberance expressed by grantees in organizing these more inclusive efforts, the breadth of actors and different contexts in which they operate further increases the challenge for funders, project teams, or researchers like ourselves to evaluate the various impacts of this work across these contexts.

Fluidity: Painting a clear picture of "*who are the users?*" is further complicated because often users' role change over the course of the project. New users not initially anticipated come into the scene or intended users drop out or become seen as not relevant. In at least one instance the researchers themselves recast their role to become the user. These changes appear to be driven by a highly fluid style of executing these types of projects, especially as their participants better understand what uses are possible and in what context. One interviewee put it this way:

> *[B]eing new to [this] kind of a Science Collaborative project, I think some of the terminology was new and I mean I knew what an end user was, but I think that there are additional end users that we didn't anticipate or think about. And so we had our collaborative team, and we had our impact on end users […] But then I think that list of end users has grown as we've discovered the lasting impact of the project.*

In part, the uncertain, fluid, and broad nature of how end users are described by interviewees shows one aspect of not only how perceptions shift but also how changes in the process of engagement with users shape the aims and practical outcomes of the project. In certain cases, collaboration with one actor, who may be a direct user, may serve to influence other possible users, who look to these individuals for guidance. For example, in several projects that sought to develop guidelines for more sustainable shoreline restoration practices, homeowners were the intended user group, yet during the project there was also engagement and collaboration with engineers, contractors, and permitting officials. This exemplifies the oftentimes haphazard nature of how knowledge production unfolds and disseminates in the context of grant-funded research. As one respondent put it:

> *And so before [homeowners] even find out about ... before they even go to get their permit, they haven't even been exposed to other ideas; so we've tried to, with some success (maybe not great success, but with some success), [to] have conversations with engineers and marine contractors about how ... they want to make ... they want a business model. So it's both assuring them and the homeowners that these are sustainable.*

3.4.2 What are the uses?

Our data also shows that there was no consistent or structured means to articulate the actual uses of project results, which stands in contrast to the funder's primary directive to produce usable knowledge. While some respondents employed very clear and direct language to describe use, the majority of the responses were less straightforward, either because their research was not ready for use due to its preliminary character or because potential forms of use were difficult to identify or characterize. As an example of direct statements of use, one respondent simply stated: *"**information was used to create a conservation plan called ___, which was presented to the town planning board and then approved…and it became an appendix to the comprehensive plan."*** Yet other responses were more vague: ***"I don't have any citable evidence of [use] right now. We could probably try to find some."***; or ***"[The work] did introduce to the shellfish managers [to] the use […] of some of this emerging technology**."* In truth, while a majority of interviewees were able to share (frequently with great enthusiasm) about some important outcomes of their work, use itself was not a discrete parameter that was easily distinguishable from other outcomes described in the course of the interviews.

During our coding, we also systematically analyzed relevant descriptions of use by applying three different typologies of use previously presented in Figure 3-1. To each typology we have added an indeterminate category to represent cases where use was neither specified nor ruled out. Table 3-4 summarizes the distribution of use types for each typology. Qualitatively, we observe no correspondence between how users are construed in terms of their geographic breadth or sectoral specificity and what kind of uses happen. As further elaborated in the discussion section, we wonder whether interviewee statements regarding use could, in the future, be more effectively elicited and articulated if provided the opportunity to articulate use through these or other typologies. The high level of indeterminacy coding—8 or 9 out of 36 projects—further supports this assumption.

Table 3-4 Three ways of accounting use of NERRS-funded research

Ryan & Neale 1943		**Pelz 1978**		**Knott & Wildavsky 1981**	
Not used	8	Not used	8	Not used	8
Indeterminate	9	Indeterminate	9	Indeterminate	8
Used	20	Instrumental	15	Reception	2
		Conceptual	5	Cognition	5
		Symbolic	0	Reference	4
				Effort	4
				Adoption	3
				Implementation	3

3.4.3 How is use recalled?

We examined the manners by which project team members recalled use. Of the 36 projects captured by the interviews, eleven did not cite evidence or even anecdotally provide examples of use. Some were at the time of the interview sufficiently distanced from the context of use and user that they had no readily available data to draw upon: ***"No, I never did circle back around and find out what they decided to use."*** For others, it became apparent that demonstrable utilization was not feasible for (or the goal of) of their work: *"**Well so far, the***

tools themselves haven't really been utilized because we didn't have any funding to develop them." Nine interviewees responded to questions about use in a relatively straightforward manner, either with a quickly recalled anecdote or data point: ***"The town planner, the one who had come to us about the project, was able to incorporate the ideas into end use planning as he moved forward."***

The remaining 18 projects, as represented by the interviews of their respective team members, provided answers that demonstrated the real challenge in recalling use. For some there was hesitation in claiming use because of general uncertainty about the evidence base and methods required to make such assertions. For example, ***"we have that kind of qualitative information. But I don't have like, 'Oh, well this regulation was changed.' I don't have more sort of concrete quantitative information."*** Or, as another example: ***"It's not something I take complete responsibility for. I was one of many researchers who were working in this area. The general idea of adding something that soaks up the chemical of concern, so that's been applied all around the world at this point."*** Others responded to the question as an opportunity to reflect about how the project changed them and their understanding of the context and potential for use, for example: ***"I basically just became aware of many, many more complexities in terms of seeing this information applied."***

3.4.4 How is use attributed?

From our interview set, we obtained responses for 31 projects regarding why researchers believed that their project succeeded, or did not succeed, in achieving use. In analyzing attributions of success across the interviews, we find that projects that fail to meet the underlying aspiration for usable science do so for similar reasons, whereas those that succeed do so for numerous different reasons. Three reasons dominated explanations for failure: either there was not enough time or money to achieve something that was usable, there were technological constraints that either rendered the resulting knowledge or tools nonfunctional, or the results were too complex for the intended user audience. In contrast, for those that succeeded, the reasons were manifold. Table 3-5 some of the reasons mentioned in the interviews. Overall collaboration or outcomes of collaboration were frequently mentioned as influencing success. In a few cases, respondents mentioned a specific policy factor such as a regulatory mandate or some other window of opportunity that made the timing of the research project particularly well suited to a successful outcome.

Table 3-5 Attribution of use and non-use within grantee interviews

Reasons for failure	Reasons for success
Technology not functional	Quality and accuracy of information
Technology not in usable form	Functionality of tool
Not enough time or money	Political window of opportunity
	Involvement of students
	Right people in collaborative
	Simplicity of method or tool
	Pre-existing relationships, maturity of project team
	Perceived importance of issue by community
	Communication to decision-makers
	Champion in user community
	Funding for implementation

3.4.5 What are the outcomes from use?

During the course of many interviews, we elicited responses about outcomes for coastal and estuarine management. These outcomes were conveyed as both "broader" impacts in relation to sustainability, as well as what might be thought of as "narrower" impacts to the participants of the project, such as psychosocial benefits of the projects to team members. These were sometimes described in isolation from, or even in lieu of, examples of research utilization.

In terms of the broader impacts to sustainability, respondents in multiple instances connected the results of their project to significant efforts in legislation, regulation, or monitoring related to coastal resources. For these cases, the interviewees were generally cautious about attributing all the benefit to one particular project but were nevertheless able to view their work as pushing in the same direction, alongside other efforts, to achieve a result that promoted more sustainable resource management. As one grantee stated:

> *I don't know if it's a straight line between a result of this project and that development happening and whatever positive outcomes for the environment that may or may not exist. I don't know how straight that line is because this isn't the only work that's gone on. I'd say with some confidence that it has played a role.*

Perhaps because they were closer to home and easier to track, a second set of impacts were narrower. These included the often quite heartfelt expressions of satisfaction that occurred as a result of the collaborative endeavor itself.

> *I mean personally […]I really enjoyed working on this project. You know, perhaps more so than other projects that are strictly science focused. I really enjoy working with stakeholders and having that kind of involvement. So it was fun for me to do for sure.*

3.5 ***Discussion***

Our results show that the effort to (co-)produce research sets in motion a number of different approaches and outcomes that defy a clear or simple assessment. Even though grantees interviewed were funded within the context of a relatively small, targeted program to produce coastal research that could be used in coastal and estuarine management, Tables 3-3 and 3-4 illustrate the wide array of users and uses that emerge, albeit through evident difficulty in recollection, identification, and attribution. The narrative about use was also generally unstructured and resulted in a substantial number of cases where use, in any form, was not possible by us to determine through analysis of our conversation with grantees. Despite these descriptive challenges, the interviewees nevertheless reported on the generation of new ideas, relationships, spin-off collaborations, and follow-on projects, outputs which oftentimes encircled the intended aim of the project in orthogonal and unexpected ways. So, when taking into account the full set of experiences and outcomes elicited through these interviews, including more ancillary but nevertheless positive outcomes, it is conceivable that systematic description of knowledge use may not be a necessary, let alone attainable, goal.

However, these projects took place through deliberate and strategic investments—by funders in terms of money, and by grantees in terms of time and relationship-building—to produce usable science for coastal and estuarine management. As such, both groups, as well as scholars who study actionable knowledge, might reasonably expect to yield a more definite assessment of project outcomes and their attribution, particularly with respect to utilization. In finding such expectations somewhat unsatisfied through this study, we find an intriguing tension between the expansive nature of co-production and the deliberate motivations that underpin its growing deployment to solve sustainability problems. Our interview data is testament to this tension. Similar to how working to produce knowledge without consideration of use leads to innovations that are difficult to envision at the outset (Flexner, 2017), it also appears producing knowledge *with* deliberate consideration of use does not result in a linear conduit to specific use. Rather, co-production presennts itself as a more winding path toward a more open-ended set of outcomes that defy the kind of tracking that would support accountability and the process of learning by doing (Cozzens, 1997; Rowe & Lee, 2012). When guided by societal challenges and driven through interaction with actors across different sectors and institutional settings, the opportunities and pathways to achieve impact are many. Indeed, our data shows that the process co-production can be both catalytic and unpredictable.

In this sense, the process of co-production fits the "garbage can" model of organizational choice. Here, knowledges, potential solutions and problems co-exist and interact as they search out windows of opportunity for alignment. Co-production does not result in prefab uses and users but, instead, can act as both an accelerator and attractant of opportunities for alignment. To paraphrase Cohen, March, and Olsen's more general appraisal of organizational behavior, co-produced science manifests itself as a collection of choices looking for problems, issues and feelings looking for decision-situations in which their tools and knowledge might be usable, solutions looking for problems to which they might be the answer, and scientists and practitioners looking for work (1972, p. 2). Yet, what may be missing in this highly stimulating and emergent context of producing science for sustainability is what Lazarsfeld and Reitz called the "first classification of the ingredients" needed to move from knowledge into action (Weiss & Bucuvalas, 1980, p. 25 quoting Lazarsfeld and Reitz 1975; 37). The overall uncertainty, improvisation, fluidity, and breadth of responses about users, and similar variation in other responses, suggest that the methodological constraints to advancing understanding of research utilization still persist (Landry et al., 2003; Larsen, 1981). In the words of Larsen (1981, p. 165) nearly four decades ago and still relevant today:

> At the present time, there is no assurance, and probably little likelihood, that what one researcher reports as indications of utilization will be comparable to what another researcher claims as utilization. When variables that are called the same name but are in fact quite different are compared, it comes as no surprise that the results are often inconsistent and contradictory.

Even though funders have since moved to more deliberately encourage co-production and adopt enhanced approaches to research evaluation, as in the case of NERRS, it is still difficult to describe, or evaluate what kinds of uses are achieved, for what reasons, and to what end. Co-production is invariably productive, but it still hard to know when intended outcomes are achieved, what broader goals are served, or how results might be expected in a different context if methods are replicated. Although this study further highlights, rather than overcomes, the methodological challenges of studying knowledge use, the results nevertheless advance our understanding of the process of deliberate knowledge co-production in relation to intended outcomes. Even within the case of NERRS, where funders are deliberate and intentional about identifying uses and users, the messy reality of research and co-producing knowledge resists attempts to systematize and typify use neatly into discrete variables. Not surprisingly, the far-from-linear process of collaborative research does not get any more predictable when it gets closer to the realm of policy implementation, which notoriously dashes hopes for a tidy correspondence between aspiration and outcome (Pressman & Wildavsky, 1984).

However, as co-production becomes more institutionalized and widely practiced, there is a growing need to better understand how different modes of science and ways of fostering interaction between science and society will meaningfully support sustainability. As such, developing a more systematic and empirical knowledge base about the drivers and mechanisms of co-production and knowledge use is paramount. We hope that future work on this topic could draw upon the typologies of use and the analytical questions (Figure 3-2) applied in this study to develop a framework for improved tracking and characterization about elements fundamental to studying, or evaluating, knowledge use.

3.6 *Conclusion*

The relationship between scientific knowledge and use is complicated. Not surprisingly, the use of sustainability science in decision-making is difficult to observe, explain and achieve. Even basic assumptions about what defines scientific knowledge use or how different forms of use advance sustainability goals can be challenging to articulate. Despite the promise of strategies such as knowledge co-production to accelerate the production of usable sustainability science, more progress is needed to understand how to incentivize and institutionalize these approaches.

This chapter has explored the connection between the deliberate effort to produce usable science with the ability to describe the fundamentals of knowledge use. Prior research has tended to separate consideration of processes for increasing use, such as knowledge co-production, from exploration of the outcome of use itself. This literature also cites persistent methodological problems in the study of research utilization. Our analysis of interviews of grantees who deliberately worked to produce usable science through funded research projects shows these challenges have yet to be resolved. Although the grantee comments typify the potential for how more engaged research approaches can be highly productive and lead toward more societally impactful research, their descriptions about the fundamentals of usability—the users, uses, tracking, attribution, and outcomes—were unstructured and in many instances came across as extemporized, speculative, and provisional. We draw on these results to speculate that more structured approaches to making assumptions about the users, uses, attribution, tracking, and outcomes could assist both future project teams, their funders, as well as those who seek to produce more generalizable insight about the drivers of knowledge use in decision-making.

However complex the relationship between knowledge and use may be, understanding more about it is critical to harnessing the power of science to serve society. There are already many well-established reasons for sustainability scientists to pursue collaborative research, but we still need to better understand and across different contexts the kinds of benefits it can produce, for whom, and how. Creating opportunities for more systematic inquiry into knowledge use, and its outcomes in practice, can serve as a foundation for how to institutionalize better ways for science to serve society. Grant supported research organized to produce usable science is an ideal context in which these insights may be more readily attained. We foresee future opportunities for collaboration between grantees, funders, evaluators, and scholars of actionable knowledge to co-produce insights and innovation about how to build a more societally-beneficial research practice.

Chapter 4. Managing Science Funding for Sustainability

This chapter is based on a manuscript under review at *Current Opinion in Environment & Sustainability,* submitted as: Arnott, J.C., Kirchhoff, C.J., Meyer, R.M., Meadow, A.M, & Bednarek, A.T. Disrupting the social contract for science? How public research funders can support actionable science for sustainability.

4.1 *Introduction*

We are at a critical moment for science and for society as we confront the magnitude of change needed for sustainability. There are many ways science can help society make progress on sustainability, and doing so would capitalize on a prime opportunity to answer mounting calls for science to deliver on what has been termed the *social contract* for science (Castree, 2016; DeFries et al., 2012; Lubchenco, 1998, 2017; Lubchenco et al., 2015). Yet our science system is largely organized to be separate from societal influence and application (Sarewitz, 1996; Stokes, 1997), making it less conducive to the kinds of engaged and interactive research approaches understood to link science with sustainability action (Balvanera et al., 2017; Mauser et al., 2013; Moser, 2016; Reed & Meagher, 2019). Widespread and growing attention to the social contract for science implies the need to reconfigure this arrangement, but it remains unclear who is responsible for, or how to implement, changes in how we do or fund science. For example, when scholars imagine how to do science differently, their focus is often on what *scientists* can do to communicate better, or engage more, with society (Lubchenco, 1998; Seidl et al., 2013). Much less attention is given to how changes in public funding, which underlies the social contract for science (Gibbons, 1999), could mainstream practices that help connect science to sustainability and other problem domains (Bozeman & Youtie, 2017; Mach et al., in review).

This chapter asserts the critical importance of program management for public science funding in the broader institutional puzzle of how science can deliver on its social contract. This begins with a brief overview of *why* public science funding should be considered within the context of discussions about the social contract. Then, I consider *how* program managers might exercise their influence to stimulate the production of more actionable knowledge (4.2). This review suggests four areas of influence: solicitation design (4.2.1), peer review facilitation (4.2.2), implementation support (4.2.3), and evaluation (4.2.4). In conclusion, I outline the need for more interactive, iterative, and evaluation-centered approaches within the study and practice of science program management (4.3).

4.2 ***(Re-)writing the social contract: who holds the pen?***

Recent appeals to revisit, or revise, the social contract resonate with longstanding critiques of how traditional approaches to science are insufficient to realize its societal problem-solving potential (Caplan, 1979; Funtowicz & Ravetz, 1992; Sarewitz, 1996; Stokes, 1997). This literature also depicts many promising alternative models for research including interdisciplinary and transdisciplinary methods (Pohl, 2008), conducting research inside the context of application and with inspiration from users (Gibbons et al., 1994; Stokes, 1997), and collaboratively producing (i.e., co-producing) science with users and other stakeholders (Lemos & Morehouse, 2005). Some scientists and science organizations have pioneered work through these models for decades or even longer (Gibbons et al., 1994; Sarewitz, 2016; Stokes, 1997), but much of the contemporary science system still encourages scientists to labor within disciplinary siloes and in isolation from applied settings and societal actors. These configurations persist even as more research demonstrates how problem-driven, societally-engaged, and collaborative research approaches can generate more actionable knowledge for sustainability (Akpo, Crane, Vissoh, & Tossou, 2015; Arnott et al., 2019; Fujitani et al., 2017; Jagannathan et al., in review.; Kirchhoff et al., 2013; Mach et al., in review; Pohl, 2008; Vogel et al., 2016).

Table 4-1 Examples of recent public funding requirements

Funding Body	Program Area	Program Feature
US National Oceanic and Atmospheric Administration	*National Estuarine Research Reserve System* (Trueblood et al., 2019)	Requires collaboration with users and evaluates changes in user context before and after project
US National Oceanic and Atmospheric Administration	*Regional Integrated Science & Assessment* (US. National Oceanic and Atmospheric Administration, 2017)	Encourages co-production and provides longer-term programmatic style funding to build relationships within regions
EU Directorate General for Research & Innovation (Horizon Europe)	*Climate Services (Climate Action)* (European Commission, 2018b)	Requires co-production and engages with small & medium sized enterprises
UK Research & Innovation	*Global Challenges Research Fund* (European Commission, 2018c)	Requires collaboration with users and host country scientists
US National Aeronautics & Space Administration	*Applied Science (Earth Sciences)* (US National Aeronautic and Space Administration, 2018)	Requires attention to application readiness; and engagement (including financial contributions) by users
EU Directorate General for Research & Innovation (Horizon Europe)	*Science with and For Society* (European Commission, 2018c)	Encourages/requires citizen science & co-production

Despite this inertia, some funders of science are now keen to explore how they can stimulate alternative approaches to research (Bednarek, Shouse, Hudson, & Goldburg, 2016; Boaz, Hanney, Borst, O'Shea, & Kok, 2018; Gitomer & Crouse, 2019; Trueblood et al., 2019). Funders are moving away from a "fund and forget" model of grantmaking (Holmes, Scarrow, &

Schellenberg, 2012), instead considering how to increase the likelihood that funded research yields actionable knowledge for sustainability or other problem domains (see Table 4-1). Though we find these deliberate efforts occurring across public and private research funding contexts (and opportunities to learn between them), the public funding landscape is perhaps most intrinsically linked with the opportunity for science to deliver on its social contract.

Within this context, program managers within public funding agencies are key actors involved in designing, implementing, and tracking the impact of funding models that stimulate alternative approaches to research. We already know, generally, the influence program managers wield to facilitate, communicate, and enforce program design changes (Clark & Holliday, 2006; Logar, 2011). Particularly relevant to linking science with action, program managers are also in an influential position to reconcile the demand for science with its supply (McNie, 2007; Sarewitz & Pielke, 2007). Furthermore, program managers in public agencies work not only in service of the scientific community but also of their larger society that calls upon—and funds—science to help solve societal challenges (Bozeman & Sarewitz, 2011; Meyer, 2011). Thus, there is potential opportunity for program managers to act as guardians of public values for science, and effect change across the largely decentralized science system that otherwise tends to resist coordinated change (NASEM, 2018).

To date, there has been little systematic examination of practical approaches public funding program management can undertake to support more actionable science for sustainability and thus enable science to better deliver on its social contract. What follows are four possible areas of influence.

4.2.1 Incentivizing engagement through solicitation conditions and criteria

The first area for influence concerns how public funders craft solicitations and other primary documents such as grant proposal guides. Of course, many public funders ask applicants to explain how their work would be valuable and useful (Davis & Laas, 2014; Holbrook, 2012), but in the spirit of our quasi-autonomous science funding culture, far fewer embed structural requirements designed to produce actionable results. This process is evolving, however, as program managers and staff shape the conditions and criteria within these documents to incentivize interactive research practices (Matso et al., 2008). Funders have incorporated user input into the design of the solicitation itself, encouraged science-practice collaboration during proposal development (sometimes with seed funding), and required collaboration of varying degrees of intensity during the course of the project itself (Arnott et al., 2019; DeLorme et al., 2016; Hunter, 2016; Moser, 2016). Seven studies published between 2011-2019 highlight how one applied science program, the National Estuarine Research Reserve System (NERRS), evolved from a traditional funding model to increasingly require grantees to collaborate with users (Arnott et al., 2019; Matso, 2012b, 2012a; Matso & Becker, 2013, 2014; Riley et al., 2011; Trueblood et al., 2019). While these progressively more prescriptive solicitations appear to influence researcher behavior and correlate with gain in research use, these findings also suggest the likely need to pursue modifications to solicitations in conjunction with other actions, such as those identified in the following sections.

4.2.2 Facilitating appropriate expertise and user input into proposal review

The second area for influence concerns how the review and evaluation of proposals is conducted prior to funding selection. Although governed by organizational protocols and institutional norms, science funding program managers make consequential choices about who they recruit to participate in, and how they facilitate, the proposal review process (Holbrook & Hrotic, 2013; Matso, 2012a; Morse, 2003). While there is little evidence that links proposal review approaches with actionability of research results, experienced program managers emphasize the importance of recruiting both information users and collaboration process experts to serve as peers in the proposal review process (Matso, 2012a; Trueblood et al., 2019). Indeed, it makes sense that reviewers need to be able to assess the quality of the collaborative processes proposed and whether the project sufficiently meets user needs. Although pursuing changes in this area for intervention is likely an essential complement to changes in the solicitation, a major obstacle in this area remains the difficult-to-change culture and institutional norms surrounding peer review (Holbrook & Hrotic, 2013; Reale & Zinilli, 2017). Studies of peer review note how disciplinary experts may have difficulty, or even overconfidence, in their ability to gauge the societal benefits or other attributes of research outside their area of expertise (Bornmann, 2013; Holbrook & Frodeman, 2011; Holbrook & Hrotic, 2013). Furthermore, even amongst communities of inquiry with similar disciplines and belief in the urgency of a problem, reviewers can express widely different opinions about what type of science is needed to support solutions (Neff, 2014).

4.2.3 Providing project implementation support

A third area for intervention is for funders to provide other kinds of support to project teams such as by playing knowledge translation or brokering roles. In this way, funders expand their mission and engage more directly with researchers and research users to support the generation of actionable knowledge (Holmes et al., 2012). This may include taking an active role in relaying knowledge produced by PI's to beneficiaries throughout the course of a project (Bednarek et al., 2016), providing on-demand resources and expert advice on collaboration processes (Trueblood et al., 2019), or facilitating end user input into the design of a solicitation or other aspects of program implementation (DeLorme et al., 2016). Funders may also connect with users before, during, and after project completion to assess the knowledge produced in the context of use (Moss, 2019; Trueblood et al., 2019). Expanding a funding agency's mission and role to aid in the production of actionable knowledge may require building capacity to support these kinds of intermediary functions. For example, supporting these new roles may necessitate the cultivation of additional skills, capacities, and funding (Riley et al., 2011), which can be constrained by prevailing logics for public science funding that champion extremely limited overhead costs. The potential for a new role for funders also raises questions about appropriate skill sets, job descriptions, and professionalization of a program management community seeking a more hands-on, interactive, and supportive role to foster the actionability of the research they fund.

4.2.4 Fostering learning through evaluation

The fourth area of intervention—evaluation—is, in a broad sense, the most extensively studied to date. Evaluation of the impact of social programs has been common for decades (Mark, Greene, & Shaw, 2006), but evaluating whether actionable science has been produced through a research funding program—or an individual research project funded through that program—carries with it significant challenges (Mach et al., in review). These challenges include disentangling attribution and contribution, dealing with time-lags between production of knowledge and use, and the highly contextual nature of sustainability action (Jagannathan et al., in review). Notwithstanding, efforts to evaluate the societal impacts of academic research are emerging in the UK (Higher Education Funding Council England, 2017), Europe (Netherlands

Organization for Scientific Research, 2014), and Australia (Gunn & Mintrom, 2018) and offer models for how to evaluate socially engaged research and make use of evaluation findings.

At a project level, evaluation efforts can help to identify impacts and how they were achieved (Gitomer & Crouse, 2019). For example, the SIAMPI framework emphasizes the concept of 'productive interactions' (i.e., "exchanges between researchers and societal actors in collaborative settings") (Spaapen et al., 2013), which can help identify which kind of exchange contributed to which kind of impact. Other approaches take impact evaluation further to incorporate social and ecological outcomes (Holzer, Carmon, & Orenstein, 2018) as well as identify indicators of quality of engagement at each stage of an engaged research (Wall et al., 2017). At the program level, multiple and comparable project-scale evaluations can be employed to assess the impacts of a program's funding portfolio and provide recommendations for program improvement (Reed & Meagher, 2019). In the private foundation context, The David and Lucile Packard Foundation's Conservation Science program apply embedded evaluation – from solicitation design to post-hoc evaluation – to improve the overall ability of their program to link science with action (Rowe & Lee, 2012). Evaluation at a program scale can also help to shed light on whether a program is adhering to its own principles for funding projects with social impact potential (Holbrook, 2010; Patton, 2017). Although these kinds of project and program-level evaluations may require changes to program planning and staff capacity, they are essential to understanding whether and how funding models for engaged research produce desired outcomes.

4.3 *Conclusion*

We are optimistic about the variety of tangible actions funders can undertake to foster a 21st century public science system capable of generating actionable knowledge and delivering on its social contract. However, we are cognizant of the complexity of the science system, the important ways it already contributes to sustainability and other problem domains, and the limitation of evidence about how changes to science funding will influence science and society. Thus, we recommend pursuing these actions strategically and adaptively through an interactive, iterative, and evaluation-centered approach that learns by doing. By interactive, we imagine knowledge exchange between funders, knowledge producers and users, and those studying science-societal interactions. By iterative, we mean that funding program design and implementation should become more explicitly viewed as natural experiments in science-society engagement. These structured experiments in program design make use of the feedback mechanism enabled by greater interactions between funders, grantees, users, and science policy researchers to inform improvements in science funding approaches—not just in science itself. An important challenge to iterativity is to institute a cycle of continuous improvement while clearly communicating the rationale for periodic change and minimizing the burden to the research and practitioner communities that rely on these funding instruments for support. McNie and colleagues describe one potential framework for organizing these efforts, which offers a much needed departure from the simplistic "basic vs applied" dichotomy that pervades research policy (McNie, Parris, & Sarewitz, 2016).

All of this, of course, is moot without an investment in the time, resources, and skill sets to conduct effective evaluation of process and outcome. Placing evaluation, the enabler of systematic, robust learning, at the center of consideration for how to pursue the emerging opportunities identified in this review, provides a critical means to guide the scholarship, program management, and practice in support of actionable knowledge.

In this review, we have identified several entry points for how public science funding program managers could influence, and even accelerate, the production of actionable sustainability science. This includes the very practical actions associated with what funders do to structure solicitations, manage the peer review process, support funded projects during their execution, and evaluate during and afterwards. While these actions are oriented around the kinds of activities funders already do, adjusting these practices may raise important questions. For example, what should the skillsets of the program managers be? What training do they need? And, what should the job description of a science funding program manager include? Program managers may also need to reconsider who constitutes the 'community' they serve and how their proximate aim to support science is consistent with their broader remit as civil servants. These considerations run parallel to explorations of questions related to the roles of "knowledge brokers" (Bednarek et al., 2018) and researchers themselves (Vano et al., 2017) who seek to shape science around these ideas.

As we enter the third decade of the twenty-first century, society is faced with the prospect of numerous disruptions to social and environmental systems. The science system has an important role to play to help society navigate these disruptions. The interactive, iterative, evaluation-oriented approach to science we have outlined here, if implemented with caution and humility, has the potential to help science fulfill its social contract and help society to better meet the challenges that lie ahead.

Chapter 5. Funding Actionable Science for Sustainability

This chapter is based up a manuscript in preparation for submission to *Research Policy* as: Arnott, J.C., Funding actionable science for sustainability: How science funding program management is writing new social contracts for science.

> *"Research and innovation (R&I) systems are currently undergoing far-reaching changes to their modus operandi. These are enabled by digital technologies and driven by globalisation as well as the increasing demand and need to address the societal challenges of our times. [...] To respond to these challenges, [we] require an increasingly transdisciplinary and multi-stakeholder approach, involving citizens and end-users, the public sector, and industry, so as to link and take advantage of unique perspectives and knowledge."* – Excerpt from a European Union funding solicitation

> *"We encourage research projects to include partners and decision-makers from relevant economic sectors and communities (across all levels of government) that would contribute subject matter expertise to the proposed research [...] A proposal needs to describe the collaborative efforts that will occur during the term of the project, and the expected partnerships upon completion of the project to ensure that the outcomes of the proposed research are assimilated, utilized,"* – Excerpt from a U.S. funding solicitation

5.1 *Introduction*

Complex issues like sustainability provide opportunities for the scientific community to contribute knowledge that can benefit society. Yet, swiftly mobilizing scientific research to meet this need at the scale required may entail systemic changes to how science is practiced. Different public funding strategies could be an important driver of these changes by supporting ways of doing science more suited to producing the kind of knowledge able to meaningfully support societal action (i.e. actionable science). To date, however, little research has assessed the potential range of approaches to funding that could stimulate this kind of science, or how funders could implement these mechanisms within public science funding bureaucracies.

Many scholars and practitioners that have considered how to generate more actionable science for sustainability emphasize the role for more use-inspired and deliberately engaged modes of research, such as scientific knowledge co-production (Kirchhoff et al., 2013; Meadow et al., 2015; Mach et al. in review). Intuitively, funding mechanisms could be expected to help realign institutional incentives, initiate cultural changes, and provide compensation for the costs of co-production and other more interactive approaches that depart from conventional research practice (Matso et al., 2008). However, science policy studies are not conclusive about if and when science funding positively influences scientific practice in general (De Rijcke et al., 2016; Holbrook, 2012; Schneider, Aagaard, & Bloch, 2016), let alone within specific context of sustainability science (DeLorme et al., 2016; Ford et al., 2013; Lövbrand, 2011).

This dissertation has previously demonstrated how program management evolution in one single funding program, the National Estuarine Research Reserve System, led to an increase in the utilization of that program's funded research (Chapter 2). The dissertation has also provided a synthesis of available literature outlining multiple areas of opportunity where funders could make changes to support the generation of more actionable science (Chapter 4). In order to consider the opportunity for mechanisms within science funding institutions to accelerate actionable sustainability science, this chapter explores the much wider, contemporary landscape for Earth, environmental, and sustainability science funding. Here, I analyze funding program documents (n=33) and program management perspectives gathered through in-depth interviews (n=61) across the U.S. and Europe. By examining what program managers in these domains are observing, what they are doing, and how they are thinking about the societal benefits of science, I ask two questions: 1) to what extent and how are public funders of science observing, contemplating, or implementing, changes to how funding program encourage societally-engaged and collaborative research practices; and 2) what are the factors that influence why these actors choose to pursue, or not pursue, program design changes that would foster more actionable science.

In exploring the answers to these questions, I provide new insight into the work of public science funding program managers. These bureaucrats are an understudied yet likely influential group of actors that may already be driving fundamental changes in the nature and process of science. Descriptively, this study provides an inventory of the many different ways these actors are observing, or working to implement, changes in how science is practiced and connects with society. This study also examines program management perspectives on how they navigate constraints within and outside of their organizational context and what they expect to see in terms of the societal benefits of science. In pursuing the realization of the social contract of science, I argue that funding managers are influenced by different factors but most critically by their management style and their expectations for how science evolves and what role it should play. In turn, this analyses of their views across different bureaucratic and geographic settings informs the different ways science funding is changing and perhaps transitioning into a new configuration of its social contract, one that more proactively seeks to stimulate actionable science for sustainability. Here, I propose a simple heuristic to both better understand how these two critical factors relate to each other and to speculate potential outcomes in terms of new models of science funding.

This study is a point-in-time investigation during a period of uncertainty, and potential transformation, across science policy in the US and Europe. Conservative political shifts and growing questions surrounding the public support of science are all occurring in the midst of global ambition for sustainable development (United Nations, 2015) and heightened attention to the speed and scale of climate risk (IPCC, 2018). At the same time, largely within the scientific community, there has been considerable ongoing discussion about how science can work to better fulfill societal expectations that accompany sustained public financial support, i.e. the social contract for science (Castree, 2016; DeFries et al., 2012; Lubchenco, 2017). This investigation into the actions and attitudes of science funding program managers reveals, sometimes quite explicitly, how they think about their role in relation to the social contract and about what they are doing to reinforce or, potentially, reimagine it.

This paper proceeds in the following way. The next section, 5.2, provides additional background to the history and prior study of funding structures from the standpoint of how they can shape the ways in which science produces public benefits. In Section 5.3, I present the methods employed in the selection of science funding programs and program managers and the analysis of documents and interview records. Section 5.4 presents results on what kind of changes are appearing in science funding competitions, the perspectives of program managers about societal impact, and the various pathways and constraints they face in implementing future change. Section 5.5 discusses these results and offers a heuristic that describes and explains different modes of funder influence on how the social contract for science is (re)configured. In 5.6 we briefly conclude.

5.2 ***Background***

Figure 5-1 Vannevar Bush keeps an eye on the lobby of the US National Science Foundation

While public science funding approaches have never been static or homogenous, the mid 20th century in the United States and Europe brought about a kind of new normal. During this time, sustained public financial commitments to science, political recognition of the importance of basic research, and the need to separate the management and practice of science from political interference resulted in a culture of self-governance that has become the custom for a large part of the science system. For example, in the United Kingdom, public funding for science emerged during World War I and explicitly emphasized, in what later came to be known as the Haldane Principle, the independence of science from politics and the critical role of basic research unfettered by considerations of use (Kearnes & Wienroth, 2009). In the United States, public support for research was expanded and further institutionalized soon after World War II, based upon similar arguments that sustained, large-scale investments in science, unconstrained by political meddling or consideration of use, would benefit society in peacetime as it so vividly had during wartime (Bush, 1945). Proponents of this model, most notably Vannevar Bush (see **Error! Reference source not found.**), helped to consolidate a largely bipartisan consensus on the value of public investments in science. Today, across the United States and Europe, science funding institutions tend to mirror these foundational principles, though with variation depending on agency mission and structure (Stokes, 1997).

Although these prevailing models for science funding and practice are widely credited with supporting many breakthrough innovations (PCAST, 2012), there are reasons to believe that, in the context of environmental and sustainability research at least, the scientific enterprise is not achieving as much value for society as it possibly could (Lubchenco, 2017; McNie et al., 2016; Sarewitz & Pielke, 2007). One shortfall occurs when scientific knowledge that is intended to be usable for society but ultimately goes unutilized, or underutilized, because users find it lacks credibility or does not fit their decision context (Kirchhoff et al., 2013; Sarewitz & Pielke, 2007). Another shortfall relates to how a predominantly self-managed science system may not always further public values in the same way it promotes scientific values (Bozeman & Sarewitz, 2005; Meyer, 2011). Those entrusted with managing public funding for science, oftentimes members of the scientific community themselves, have the difficult task to straddle the boundary between serving as guardians of both public and of scientific values, which are not always consistent with each other (Bozeman & Sarewitz, 2005). Furthermore, the performance of this task is not well studied, and we are unaware of any studies that systematically explore the perspectives of science funding program managers in performing this work.

A large portion of public funding for science is administered through a competitive grant model. Programs within public agencies issue calls for proposals to a particular discipline or topic. Submitted proposals are reviewed, typically by a panel of peer reviewers. Based on this review and funding availability, a subset of proposals are selected for funding. Once awarded, grantees proceed with the proposed work, though typically with latitude to deviate, within reason, from the proposal. At the end of the research project, a report on results is submitted to the funding agency, within a period of typically 90 days or less. Program managers play a key role at each stage of this process: formulating and issuing calls for proposals, selecting participants for and facilitating peer review, making funding recommendations (if not decisions), and vetting reports upon completion. Frequently, these individuals or their associates interact with researchers before, during, and after the grant making process, thus serving as a main point of engagement between the research community and science funding agency. It is common that these individuals are respected members of the scientific community and they often have specialized training in the discipline or areas of study they fund.

Science funding program managers are bureaucrats and, oftentimes, civil servants. To the extent they exercise discretion and pursue innovation in policies and practices within their purview, they may be considered makers of (science) policy. Policy science theory and empirical research have highlighted how some bureaucrats exercise surprisingly high levels of discretion that amounts to an outsized impact on their policy portfolio (Page, 2012). In the context of sustainability science, there have been efforts to explore how program managers could leverage their influence to produce more actionable research (Clark & Holliday, 2006). In particular, growing interest in more collaborative modes of co-producing research with potential users raises the question about how funders can possibly encourage or, even mandate, these practices (Arnott et al., 2019; Matso et al., 2008). Ultimately, as with other aspects of research on funding program design, limited evidence is available on how funding program management influences the actionability of sustainability science. Notwithstanding, as elaborated further in Chapter 4, there are a range of opportunities for changes to science funding program management that could help generate more actionable knowledge. We briefly encapsulate these opportunities below.

5.2.1 Solicitation conditions and criteria

The way calls for proposals are structured can stimulate researchers to think about, or incorporate plans for action that deliberately pursue, societal benefits during the research process. Ford and colleagues (2013) found that even when a funding program has an aspiration to produce usable science, that aspiration alone is not sufficient to stimulate the kinds of research practices, such as knowledge co-production, needed to increase the likelihood of knowledge use. Thus, the solicitation for proposals can be a starting point to mobilize additional steps needed to accomplish this goal. For example, re-designing solicitations to incorporate recommendations of, or requirements for, research practices such as co-production and establishing new criteria for review that helps to enforce consideration of impact into the proposal can potentially influence changes in the outcomes of the sponsored research. In the past few years, several studies have linked funder requirements for more interaction between researchers and potential users with higher rates of utilization and other outcomes (Arnott et al., 2019; DeLorme et al., 2016; Hunter, 2016; Moser, 2016; Riley et al., 2011).

5.2.2 Panel review and facilitation

Peer evaluation of proposals for public funding is a cornerstone—and consequential component—of our largely self-managed science funding system. Reviewer qualifications and panel facilitation can significantly influence what kind of research is funded (Morse 2003; Bornmann 2013). Even within the same or similar disciplines, reviewers can express widely varied judgements about the most appropriate type of science to fund (Neff, 2014). Consequently, who gets to be a peer, or how other changes to the peer review process should be implemented, are highly sensitive questions in the funding community (Holbrook & Hrotic, 2013). Some examples of attempts to change peer review yield limited impact due to the tendency for scientists to work to preserve the status quo (e.g., Reale & Zinilli, 2017). In addition, questions about peer review raise difficult-to-answer questions about who is capable of evaluating the public benefits of science, or, more precisely, what kind of proposed research is more likely to contribute to specific societal problem solving. Despite hurdles to change and a limited evidence base, experienced program managers emphasize the importance of modifications to the peer review process, such as by including information users and collaboration process experts (Matso, 2012a; Trueblood et al., 2019).

5.2.3 Project implementation support

Funding organizations may have the capacity, the network, and the knowledge base to provide additional means of non-financial support to projects they fund. Making these resources available to grantees could increase the overall capability of a funding program to achieve desired goals. To do this funders may, for example, serve as bridging organization themselves, connecting current or prospective grantees with decision-makers and other contexts for application or by providing support on overcoming the challenges of implementing collaborative science (Bednarek et al., 2016; Matso & Becker, 2014). While this role for funders has shown promise in some reported examples, it raises questions about the capacity of funders, their proper role, and the qualifications and characteristics of the personnel employed by science funders.

5.2.4 Evaluation

Research evaluation is already widely pursued as an instrument of research policy (Gunn & Mintrom, 2018; HEFCE, 2017; Netherlands Organization for Scientific Research, 2014). Thus, funding organizations may be able to leverage different approaches to influence what kinds of (or how much) research outputs and outcomes are produced. For example, at the national level, science funding councils have built upon more conventional assessment of research performance, such as citation indices (Bloch & Schneider, 2016; Schneider et al., 2016), to condition future allocations of funding based on the demonstration of societal benefits (HEFCE, 2017). While these changes have been shown to have some effect on researcher behavior— in the case of citation-based research evaluation, not always positively—the evidence for how any type of research evaluation influences researcher behavior remains limited both because evaluating societal benefits is difficult (e.g., time lag, attribution, etc.) and because data is often not available (Arnott et al., 2019; De Rijcke et al., 2016).

5.3 *Methods*

5.3.1 Selection

For this study, I selected US and European science funding programs in the areas of Earth, environmental, and sustainability science. Within this domain, I selected competitive research grant funding programs and excluded programs that were oriented around fellowships, internships, conference support, service delivery, environmental restoration or remediation, and funding for large research centers or infrastructure. The sample included a large amount of funding for environmental and sustainability research, enabling a relatively broad perspective into how funding is changing (or not changing) amid different institutional, political, and cultural contexts.

In the United States, initial funding programs were identified through systematic searches on grants.gov for both current and recently closed competitions. Solicitations identified during this phase were cross-referenced with narrative descriptions of different agencies' participation in the U.S. Global Change Research Program, an entity that coordinates and accounts for the cross-section of many Earth and environmental research funding programs within the United States. This initial selection was further augmented by recommendations from eventual interviewees, resulting in 22 current or recently concluded program competitions for research grants. Solicitations (or RFPs) for each of these programs were downloaded whenever available, and program contact points were placed into a database for interview recruitment. For some programs, no current or recent solicitations were publicly available, but contact points for programs were identified and invited to interview.

In Europe, selections at both national and EU levels were determined through the review of funding agency websites, prior knowledge of funding landscape, and input from several in-country hosts. Similar to the United States, selection focused on programs that were organizing competitive research grant support. Here, I selected four national programs—the UK, Germany, Switzerland, and Italy—both for their representativeness of different sizes, national research budgets, and geographies, but also for the practical consideration of needing to conduct interviews in English. Contact points for these programs were recorded, and additional contact points were sought as recommendations from in-country hosts. A total of 11 programs were identified.

The result of this selection process represents at least USD 750 million in annual public support for sustainability and environmental research. These included programs dedicated to basic and applied research funding as well as a mixture of programs within both science and mission-oriented agencies. While the findings presented in the results should not be taken to necessarily represent the distribution of funding approaches writ large, they are likely indicative of the breadth of different funding approaches and the kinds of motivations and factors that shape public science funding today.

5.3.2 Interviews

Names listed in program documents contributed to a core set of individuals recruited to interview. During most of the interviews, I collected additional names of people to interview. 125 individuals were invited. This resulted in a mixture of individuals that perform the core program management function for one or more competitive grant programs (which we call "line officers" for the purpose of distinction), other program support staff who serve either as the contact point for applicants or manage other activities such as evaluation, senior-level directors who oversee groups of program managers, and individuals who have been actively involved in public science funding program management previously in their career but who now occupy other senior positions inside and outside of government. 61 individuals participated in 58 interviews (three interviews were conducted with two program managers at the same time at the request of the interviewees). Interviews were conducted between August 2018 and February 2019. I met with 51 of the interviewees in person, and the remainder were conducted by either video teleconference or telephone. Two-thirds of the interviews were recorded and transcribed. For the remaining third, hand-written notes were taken during the interview and soon after compiled into a summary of interview, with direct quotes indicated wherever possible. A summary of statistics about interviewees is provided in Table 5-1. Overall, these interviews were lengthy (on average lasting over 1 hour) and involved participants with long tenures in the realm of science funding program management (on average 11 years).

Table 5-1 Program manager interview summary statistics

	US	EUR
# of people interviewed	**31**	**30**
Line officers	*22*	*15*
Program support	*2*	*12*
Senior directors	*5*	*3*
Other	*2*	*0*
Average length	70 minutes	65 minutes
Average years of experience*	12 years	10 years
Gender balance (% female)	29%	37%

Interviews were conducted in a semi-structured format based upon a questionnaire developed in advance (see A-6, page 130). Because of the position of authority of many of the interviewees and sensitivity regarding the subject matter, I followed techniques of elite interviewing as set forth by Dexter (1970). The interview setting was flexible enough to allow for a wide-ranging and frequently personable conversation, while also attending to the key questions for this study. Per agreement with interviewees and IRB protocol (HUM00147365), their identity and the specific programs selected for this study are not disclosed.

5.3.3 Analysis

Analysis of program documents and interview records was conducted using qualitative content analysis (Miles et al., 2014). Solicitations associated with programs selected for this study were downloaded and organized into a database. These documents were initially reviewed as part of background research for interviews and then later systematically analyzed in NVivo to produce a database of strategies and techniques that funding programs are employing. The analysis of this data is presented in the second results section.

Table 5-2 Coding structure for program manager interviews

Theme	**Description**	*Subthemes*
Describing change	Remarks where program managers described changes (or lack of change) in the practice and funding of science	• Changes in how science operates to produce societal benefits: • Changes in the societal context for practicing (and funding) science: • Persistence (i.e. lack of change)
Practices for change	Remarks where program managers described practices employed to shape the impact of funded science on society (based on Chapter 4)	• Solicitations • Panel • Support • Evaluation • Other
Implementing change	Remarks where program managers describe how they currently implement, or might implement future changes in how science produces impact for society	• "Community" • Discretion • Capacity • Evaluation

Detailed notes and transcripts of interviews were also analyzed using NVivo software. We coded interview texts for comments that pertained to one of the central themes of this study summarized as: describing change, theorizing change, and implementing change. Subsequently, a second-cycle coding procedure systematically coded passages within each theme into a series of subcodes (see Table 5-2). For each subcode, a set of keywords were attached to different statements to support the comparison between interviews, which enable numerical tracking of their frequency of mention for reporting in the following tables

5.3.4 Study limitations

Although this research provides the opportunity to understand the perspectives and actions of a difficult-to-study segment of the science system, there are several limitations. In selection of programs in the US, I confined my search to current or recently closed funding competitions within relevant topical domains, which excluded shuttered or infrequently solicited funding programs in some agencies that could have provided further, or different, insights. The selection process in Europe was also limited due to the lower number of funding programs and personnel represented in this study per unit of governance. In the analytical process, I followed standard protocols for qualitative content analysis to the extent possible by a single researcher, which imposes limitations on coder reliability. Furthermore, the wide-ranging nature of the semi-structured interview protocol meant that some interviewees may not have spoken to a theme that they could have if specifically prompted. All these factors stress the importance of interpreting these results as a field scan to assess the breadth and diversity of actions and perspectives within the science funding system rather than a generalizable representation of how all science funding is evolving.

5.4 ***Results***

5.4.1 What program managers are observing

Interviewees were asked to remark on whether or to what extent they have observed changes in the scientific enterprise from their standpoint as science funders. Follow up questions probed for further detail about both changes in how science is practiced in their domain as well as how funding for science is administered in general. This line of questioning, in most cases, led to observations specifically about how science is changing in the way it relates to society and the way it organizes to produce societal benefit. Additional observations related to how the administrative and societal context for science is changing. Table 5-3 provides an accounting for when each of the following themes (**bold**) was mentioned during the interviews.

Generally, many interviewees (35) recognized a growing recognition across the science system that science should deliver more benefit to society. As put by one U.S. interviewee, *"Those that were at their prime in the [19]60s, 70s, and 80s were part of the boom in science for science sake. Now we're asking: why and what for?"* As a European interviewee put it: *"I think there's definitely a recognition now that you can't be in an ivory tower and not expect the mob to burn it down."* Such statements reflect how science funding program management is attuned to the mounting calls for the scientific enterprise to do more for society. Several other interviewees (5) specifically linked rising attention to the public benefits of science with the concern of waning public support for science. Said a US interviewee, "*we [i.e. scientists] were treated like gods three decades ago; those days are over.*" For some, these diminishing views about science pose serious risks to the continuation of a relatively stable period of public support for science, particularly when considered alongside the demand for government to provide more of other desirable public goods like healthcare.

More specific observations about if and how science was changing to respond to rising interest in the societal benefits varied. Nearly half (25) of the interviewees identified changes that either specifically referenced, or substantially described, the practice of knowledge **co-production** with users. While this evolution has occurred over different timescales in different programmatic contexts, many of the interviews reflected the comments of a US manager who described the transition in this way: *"There's definitely more of an emphasis on articulating […] the importance of co-production and boundary organizations. As we saw teams adopting more of a co-production model, they were making more inroads with stakeholders, and the stakeholders were really loving that model."* Similar comments were offered by interviewees in Europe at both the EU and national level. As put by an interviewee in Switzerland:

> *the way how stakeholders or practitioners are involved in research projects is much more intense. It's […] not all the time but there are grant proposals who really have the stakeholders involvement and […] co-production of knowledge. […] The use-inspired research and transdisciplinary research is evolving and […] the community was smaller 10-15 years ago than it is today*

Related to the shift toward co-production, fifteen interviewees observed trends toward **technology transfer or translational** modes. As put by U.S. program manager, there is increasing emphasis to *"ensure that the connections are made between that research and how it actually moves into operation."* Efforts in this direction include focused strategies towards commercialization and step-by-step tactics to support progress to application at each stage of research. Another somewhat overlapping group of fifteen interviewees mentioned changes in either the expectations for, or practice of, **communicating and engaging** with society. In contrast to observations about more meaningful interaction between scientists and users during the process of research, this theme focused on the work of scientists to disseminate and engage with various societal actors about research results as an activity separate from the research. For example, interviewees pointed to the growth in expectations for researchers on *"telling the story"* of their science or to *"show the results in front of policy makers."*

Despite sharing many observations of changes underway, some interviewees provided accounts about the **persistence** of both their funding program design as well as more general norms surrounding research practice. Twenty-three interviewees remarked on the general continuity within the science system, including several who also commented elsewhere in the interview about where they see changes happening. Most of those speaking to the persistence of science funding structures and norms referred to the continuation of standard models for funding basic research or about the perpetual distinction between basic and applied research. With regards to co-production and other forms of more societally-engaged research, two interviewees indicated that this model has been around for decades or longer and thus in their opinion did not constitute a change but instead the continuation of a successfully mainstreamed approach to research.

While not specifically prompted by my protocol questions, interviewees observed other changes within science funding management that relate to how science is practiced and managed. For example, many interviewees from the United States, and a couple from Europe, remarked on the increase of **accountability** and related paperwork associated with the effort of science funding program management. One US interviewee remarked: "*I think being a PI has become a lot worse over the decade: there used to be more free will displayed towards investigation. Now they have to answer a lot of mail."* This theme was less prevalent in Europe and in some cases interviewees there remarked on approaches in development, or under consideration, to *reduce* the administrative burden for science. While the theme related to accountability does not directly overlap with the sense of accountability related to the public benefit of science, it is interesting to see how research systems already assert many forms of accountability in the form of red tape, thus somewhat challenging the existence of an idealized model of unfettered, self-governing science.

A prevalent theme of change throughout European interviews (13) was a rise in the **internationalization** of science, which in this context referred to an increase in international collaborations and the flow of scientific talent throughout Europe and beyond. In some cases, these mentions directly linked to science policy strategies aimed at increasing the international competitiveness of national funding programs, but in other contexts this theme arose in conjunction with other national policy strategies, such as the strategic employment of scientific institutions to support international development agendas. Interviewees in both the U.S. and Europe reported changes in program management tactics having to deal with "**flat cash**," or level budgets, and the concomitant dwindling of, or persistently low, **success rates**, that necessitated in approaches like multi-step review procedures and other means of staging the application process to reduce burden on applicants and reviewers. Another prevalent change mentioned by most interviewees shifts to incentivize **open access** publishing and other forms of "open science." In both the US and Europe, these changes are attributed largely to top down executive actions or high-level science policy decisions aimed toward increasing the openness and accessibility of scientific data. Also, some interviewees pointed to discussions of **diversity in science** and their role in fostering changes to encourage more inclusion of underrepresented groups in science.

Other interviewees pointed to the changing **politics** of science funding, either in the broad sense of major upheavals in political structures brought about by the rise of populism (e.g., Trump or Brexit), or by smaller political changes, such as the rearrangement of agency structures or the desire for more political involvement in funding. Some reported the emergence of more politically **directed funding** to support research on particular topics identified by policy-makers (which could be conceived as a form of co-production, albeit an additional form to what was previously coded). In this context, some interaction effects were observed. Several in the US who remarked about recent political shifts, for instance, pointed to this as an opportunity to encourage practical measures like co-production to increase the societal benefits. In these instances, there was the suggestion that such political changes were providing the opportunity space for funding program changes that could strengthen connections between researchers and potential users.

Table 5-3 Mentions of institutional change by program managers

Related to societal impact	US	EU	Related to the scientific enterprise	US	EU
General	14	21	Accountability	8	2
Communication & outreach	8	7	Flat cash	5	3
Translation & technology transfer	12	3	Success rate	4	8
Co-production	10	14	Open access	6	6
			Diversity & inclusion	1	3
			Politics	3	1
			Directed funding	2	2
Refer to corresponding emboldened phrases for descriptors of themes.			Internationalization	0	13

5.4.2 What program managers are doing

Interview transcripts and the set of available program solicitation documents are, in many instances, reflective of the broader trends observed. Of the 33 solicitations reviewed in this study, nearly two-thirds contain aspirations for societal impact of the science they fund (21), with a comparable number requiring researchers to describe how they will achieve societal impact (23) and at least encouraging (if not requiring) researchers to engage with non-researchers to help ensure impact (20). The particular approaches taken within each solicitation vary with respect to specificity and intensity of obligation imposed upon the researcher. For example, some solicitations only speak briefly, and at the most general level, to the aspiration for societal benefits, whereas others enumerate the specific sectoral or geographic contexts for which research effort is expected to contribute benefit. Additionally, some solicitations reflect a bottom-up approach that invites researchers to define their topics, approaches, and contexts for intended application, whereas other funders use the solicitation to provide a specific scope and set of directions about what kind of, or how, impact will be achieved. European funding programs sampled for this study, on the whole, were more likely to contain the types of aspirational statements or conditions evaluated in our systematic search (see Table 5-4).

Table 5-4 Solicitation components related to societal impact and engagement

Funding Solicitations	**US**		**EUR**		**Total**	
Component Type	*n (of 21)*	*%*	*N (of 12)*	*%*	*N (of 33)*	*%*
Aspiration for societal impact	12	57	9	75	21	64
Statement for societal impact*	12	57	11	92	23	70
Encouragement for societal engagement	5	24	3	25	8	24
Requirement for societal engagement	5	24	7	58	12	36

*Includes optional requirements and when not explicit but clearly embedded within program guidance

Through interviews, program managers mentioned a large number of practices that they have recently pursued to increase the applicability or societal benefit of the research they fund. These included practices explicit in the solicitations reviewed for this study, as well as practices from other recent solicitations or relevant to other aspects of program management.

Table 5-5 provides an inventory of these mentions sorted by categories of program management interventions presented in Section 5.2. These results show that there are numerous specific types of practices occurring within each area for intervention. While there are some more evidently common practices, such as encouragement or requirement to engage with users during the course of projects, or to include users on review panel, the overall results depict less convergence and, instead, wide-ranging experimentation.

Table 5-5 Program management practices mentioned by program managers

	US	EUR	Total
1. Solicitation design (encouragement/requirement)			
Grantees engage with user during project (grantees determine who)	3	8	11
Grantees engage with user during project (funder determines who)	4	0	4
Grantees include impact statement in proposal	0	4	4
Grantees engage with user during proposal generation	2	1	3
Grantees apply using alternate proposal formats	1	0	1
Grantees engage with public	1	1	1
Grantees include letters of support in proposal	1	0	1
Grantees employ project manager	1	0	1
2. Peer evaluation to guide selection			
Funders include users on review panel	5	4	9
Funders emphasize, or provide training on societal benefits, during panel facilitation	2	3	5
Funders include diverse expertise on review panel	2	2	4
Funders request in person presentation to panel	0	1	1
3. Project implementation support			
Funders conduct monitoring and engagement with grantees during project	2	2	4
Funders provide cross-cohort coordination & support	3	0	3
Funders include users on advisory boards	1	1	2
Funders communicate/synthesize research	0	2	2
Funders convene events to explain solicitation	1	1	2
Funders convene users and researchers	0	2	2
Funders prepare guidance for user engagement	0	2	2
Funders convene sandpits, ideas labs to generate ideas for proposals	0	1	1
Funders provide extra funding for implementation	0	1	1
Funders provide support for proposal preparation	0	1	1
4. Evaluation			
Funders conduct program evaluation of societal impact	0	4	4
Funders evaluate use by non-researchers using grantee reports	0	3	3
Funders encourage researchers develop their own metrics of impact	1	1	2
Funders evaluate use from user perspective	0	1	1
Funders draw upon informal/anecdotal based evaluation	0	1	1
Funders provided framework for evaluation for researchers to apply	1	0	1
5. Other			
Funders coordinate with other programs within agency to maximize impact	3	0	3
Funders coordinate with other funders to integrate basic and applied	1	1	2
Funders support early career researchers doing challenge-driven research	1	0	1

5.4.3 Factors shaping implementation

Interviewees were asked about what they see as the role of science funding (and funder actions) in shaping the societal benefits of science, as well as how they consider implementing change within their agency. This line of questioning brought to light different factors that both propel and impede making changes to how science is funded. In the design of this study, questions in this part of the interview were intended to probe interviewees about the amount of discretion they exercise in crafting and implementing changes to funding program design, with the aim to explore the extent to which program managers can act as de facto science policy-makers.

A dominant theme in many interviews was how funder perceptions of the "community" influence program management actions. By "community," respondents across the US and Europe were most frequently referring to the *research* community, either specific to a disciplinary domain or more broadly. This comment from a European interviewee typified the theme surrounding this constraint: *"Any drastic changes that you make to the process, you need to go through a consultation with the community and understand the impacts."* However, interviewees differed in terms of how they construed their role in relation to the research community. At one extreme, in the words of one German manager: "*I think this is most important to know [..] that the program manager is really just having not much influence on any processes. So yeah you just have to work for the community-based wishes."* On the other end, some program managers pushed back against this presumption regarding their role, such as a UK Program Manager who posed this question and comment: "*Who is the customer and who's the supplier? I think a lot of the academic community look on themselves as the customers of [our agency], whereas to me, they're the suppliers and [the public] is the customer of what we do."*

Others see the orientation around community interests as a hurdle to overcome in order to reshape their program according to their desire, as summed up by one US manager, *"[Office of Management & Budget] and Congress want to see what the scientific community thinks about a topical area. As a program manager you need to point to a bigger voice."* One was blatantly impatient by the impediment posed by the community saying, *"I've waited [as the other agencies] dither on what the community wants,"* and then continued to describe approaches they took to shape their program more proactively without community buy-in.

While those interviewed in every organizational and national setting wield some degree of power through their role in the process of competitive grant funding, particularly in areas such as panel composition and facilitation, the amount of discretion available to program management over the design of the funding program also depended on the organizing principle for and type of science being funded. In both the U.S. and Europe, programs intended to support basic research on topics identified by the research community rely upon structures and procedures that appear more difficult program managers to change. For example, one program manager in this type of setting stated that any changes to program structure would not be possible for a program manager to make, whereas change to protocols would be possible if *"larger parts of the scientific community come"* to the agency to propose changes.

However, within funding organizations charged with missions other than funding basic research, or even within basic research funding organizations with programs using targeted or societal challenge driven research programs, program managers described a great deal of discretion available to them in how they design their program and pursue innovations in protocols. From US contexts, comments were made such as, *"Leadership here encourages program manager to find new ways of doing things,"* or *"One of the reasons I enjoy being at ___* *is because of the autonomy we have, the ability to craft your program, direct your program,"* or *"my role is never being satisfied and looking for a new way to do things."* From the European interviews, similar opportunities for discretion were described. Freedom to reshape program designs were possible *"as long as we have a rationale for it,"* said one interviewee. Another claimed, *"we [i.e. program managers] basically do policy for science. […] We draft, we sort of hold a creative pen as it were."*

Aside from how notions of "community" and the norms around researcher autonomy in the context of basic research influence how program managers exercise their discretion, other constraints on the ability of science funding program management to implement changes included the easier-to-predict constraints related to time and money. Funding programs are typically lean operations in terms of staff and overhead with large numbers of grants and funding amounts managed by a small number of agency staff.[2] One consequence of this is that there are few extra resources for conducting evaluation and other forms of program support and analysis. Said one U.S. interviewee, "*I think we need to step back and look thoughtfully at what we're doing. But we don't have enough people. I suppose you could have a separate group on assessment."* In Europe, there was more emphasis on evaluation, broadly construed, though not necessarily focused on outcomes pertaining to the societal uses or benefits of research. Furthermore, evaluation activities were not always synchronized with the decision-making processes of program managers, which consequently meant that program changes were not necessarily informed on the basis of these evaluations. As a UK interviewee charged with the evaluation work for their program area said, "*the way research is funded and evaluated adapts to reflect wider contextual changes. It will take too long if you wait for the evaluation process to*

[2] For example, in 2007, the National Science Foundation's Office of Inspector General tabulated the NSF overhead rate at 5.8%, a staggeringly low amount when compared to overhead at organizations that conduct research.

change. You need to learn faster than that. We don't always wait for an evaluation to change." Similarly, at the EU-level, although evaluation informs the transition from Horizon 2020 to Horizon Europe (e.g., EU Commission - Directorate-General for Research, 2018), the design of Horizon Europe does not yet take into account the experience of the second half of Horizon 2020, in which some of the more concerted efforts around co-production were implemented.

5.5 ***Discussion***

The results of this study depict a transition underway in terms of how some funding programs are organizing to support more societally-engaged and -impactful research. This is possible to see both through the lens of what many science funders who participated in this study are *observing* from their position at the science-policy interface (a unique and privileged vantage point), but also what they are *doing* in the form of making changes, or deliberately deciding not to change. These results help to cast science funding practices, and the role of science funding program managers, into a new light as instrumental actors shaping the science-policy interface. Because many of the perspectives and practices documented in this study overlap with the kinds of changes to research practice understood to increase the actionability of science (e.g., knowledge co-production), these results signal the possibility of science funding as a means to stimulate and expand the link between sustainability science and action.

Innovative approaches to organizing research and research funding are proliferating even as conventional models and norms about research autonomy and the separation between basic and applied science still apply. As mentioned in the results surrounding *persistence,* in some cases, standard models are being proactively protected, even while many recognize a groundswell of change in terms of the expectations, or desire, for science to better serve society. Funders have the potential to pursue—and many already are pursuing—opportunities for intervention across the full life cycle of the research process, including solicitation design, proposal review, implementation support, and evaluation. This includes practices that seem explicitly aimed at fostering closer interaction between researchers and societal actors during the research process itself. This can be seen through the actions made in the spirit of incentivizing co-production, but also in other ways of proactively fostering societal outcomes, such as innovative convening approaches that bring researchers together with users during the grantmaking process. The great diversity of these approaches documented here (see Table 5-5, for example), without any apparent sense of convergence or centralized strategic direction, suggests a proliferation of experimentation in the science funding system. While this evidence suggests the many possible avenues for influence in shaping the use of sustainability science, a lack of systematic evaluation limits the amount we can actually learn about the relative outcomes of these interventions.

Although the extent of the impact of the changes funders are making is difficult to gauge, the results of this study further characterize science funders as influential agents in creating, revising, communicating, and enforcing social contract*s* for science. The actions and perspectives documented here show ways in which science funders are, to extend the metaphor, picking up the pen and drafting numerous alternative versions of these contracts. For example, by tweaking the ways in which funding programs are structured to specifically require different forms of engagement with society (or not), or make demands upon researchers for usable results or other benefits (or not), funders create various sets of expectations for researchers to choose from with respect to how their research connects with society.

From the funding program documents and program manager perspectives observed in this study, these actions take place across a spectrum ranging from concerted effort to preserve a space for bottom-up, curiosity-driven, and unfettered research to proactive measures undertaken to reshape the scientific enterprise to more forcefully contribute to societal challenges. As an example of the former, one interviewee explained their deliberate actions to justify and preserve a type of autonomous science independent from funder, societal, or political influence:

> *[W]e are not sort of having this funding model because of tradition, or because […] we just don't want to change, but we do believe that [there] are functional reasons why there should be at least a segment within the science system where the subjects are chosen by scientists and where scientific quality indicators should count.*

In contrast, another interviewee explicitly employed the language of the social contract and the evolution of societal significance of climate and environmental issues to justify their changes:

> *And because now in particular climate change and other environmental issues have left the science-only domain and they have become citizen-relevant, policy-relevant, societally-relevant, or whatever the right word is.* ***We say that we need a little bit to change the social contract in a way, so we cannot have simply actions for scientists to work with scientists.*** *Then the only thing we want out of taxpayers money is a couple of publications in top journals. This is not enough for us anymore.* ***(emphasis added)***

The notion that science funding program managers are contemplating, or in some cases actively seeking to reconfigure, the social contract for science portrays these actors in a new light as de facto makers of science policy. These results highlight potential means by which funders, through bureaucratic discretion, can implement relatively small-scale changes in their program management that may have more profound changes on the science system. Although many spoke to the influence of higher-level changes that constrain or impel certain actions, I found that the exercise of this discretion was influenced less by organizational constraints to their authority (e.g. bureaucratic strictures) than by their own beliefs about the appropriate role of science funding program management and what kinds of societal benefits society should expect to see from science.

Figure 5-1 builds on our results that describe what funders are doing and the factors that influence their actions to represent, more generally, different pathways of funding science. Here, different combinations of program management style and beliefs about the societal function of science result in different modes of science funding and imply different expectations for publicly supported research. A *proactive* program management style can employ direct engagement with grantees and deliberately modulate program components like solicitations, review panels, and evaluation to try to better achieve program goals. In contrast, a *passive* program management style is more cautious and considers changes to program design mainly in response to concerns that arise from the research community or from higher levels of bureaucratic authority. These divergent management styles can intersect with different expectations for the societal benefits of science. One expectation is for sponsored research to support societal *problem solving*, such as through generating knowledge that can inform sustainability decision-making and other more pragmatic outcomes. An alternative expectation is for publicly supported science to further *discovery*, a kind of intrinsic benefit to society.

The four resulting funding approaches, each of which were encountered in the programs selected for this study and typified by different interviewees, may help to depict different ways in which funding programs are influencing changes in science and its relationship with society. For example, when funders proactively seek to foster science that links with action and encourage research practices such as co-production (A), this approach departs substantially from when funders work in response to "community" needs (i.e. the *research* community) and champion the scientific values of curiosity-driven, autonomous research idealized by Bush and institutionalized, to varying extents, in many public funding agencies (D). The other two approaches—B and C—are intermediaries between these extremes. For instance, some program management contexts adopt a similarly passive approach to (D) but operate in a mission-oriented or societally-challenge led context where their belief about the societal function of science is more focused on the practical applications. In this setting, the resulting social contract for science is less demanding for what kinds of impacts are achieved or how, anticipating that researchers will exercise their own discretion about how to proceed (C). When beliefs about the societal function of science focus on the expectation for discovery but take on a more assertive management posture, program managers can introduce more levels of accountability for encouraging and/or tracking particular levels of activity or research excellence. This could involve more proactive measures by program management to collect data and communicate research impacts to various higher-level decision-makers and science policy makers (C).

Funding management approach	Expectations for science: *Problem solving*	Expectations for science: *Discovery*
Proactive	**A. Action**	**C. Accountability**
Passive	**B. Anticipation**	**D. Autonomy**

Figure 5-2. Science funding and the (new?) social contract for science

This heuristic could serve as a basis for further examination of the influence of science funding on how the social contract for science is constructed and enforced. However, just as scholars debate whether an altogether new social contract for science is required (Castree, 2016; Gibbons, 1999; Lubchenco, 1998), or if science needs only to better deliver on the original (DeFries et al., 2012; Lubchenco, 2017), these different approaches to funding could suggest either multiple pathways to deliver on a single longstanding social contract or, alternatively, the diversity of ways science should contribute to society.

5.6 *Conclusion*

How science is funded inevitably shapes science and how it (dis)engages with society. The science funding practices and perspectives examined through this study help us better understand the efforts and underlying motivations of funders to shape how science interacts with society. Specifically, we witness a wide variety of means funders within the Earth, environmental, and sustainability domain are employing to encourage strategies like scientific knowledge co-production, which is predicted to increase the actionability of science. From modifying the conditions and criteria of solicitations to encourage co-production, to revising how projects are evaluated before funding and after completion, to embracing the concept of co-production internally within funding agencies to guide program development, there is a deliberate effort in many agencies to further connect knowledge into practice to inform sustainability decisions and actions. At the same time, the perspectives of interviewees highlight a tension between this movement and the persistence of (or resistance to changes in) features of the science system that have long been held dear by the scientific community.

In the context of Earth, environmental, and sustainability science domains, at least, these observations suggest that funders are responding in different ways to the mounting calls for science to deliver on its social contract by helping to implement structural changes to the institution of science that increase research use and other potential societal benefits. At the same time, however, we find that this momentum is constrained by the persistence, even amongst those keen to experiment with alternatives, of more traditional arguments for the autonomy of science and the separation between the work to make fundamental discovery and the work to apply it to help solve societal problems. And, ultimately, making progress on discussions about how different approaches to science funding serve society better requires a more systematic and intercomparable approach to science funding evaluation, the lack of which many of those interviewed lamented.

While public support of science is central to the scientific enterprise and the fulcrum around which science policy pivots, the mechanics of public science funding remain a neglected area of research. Although many will argue for more funding, or different types of funding directed at various priorities, little attention is paid to what funders are actually doing and what influence their actions, even at the scale of solicitation design, can have on the scientific enterprise. More attention in this area is needed if we are to substantiate the intuition that funding has a role to play in driving knowledge use for sustainability. Furthermore, we may find that closer attention to the mechanics of, and underlying logics and motivations surrounding, the management of public science funding will shed light on the social contract for science: if and how it is changing and what the implications are for the future of the relationship between science and society.

Changes in the way science is practiced and used affects not only scientists and research organizations but can also critically influence the role it plays in helping society to advance societal and ecological well-being. As the need to address grand challenges like climate change grows, it is more important than ever to understand how to create actionable knowledge. This research seeks to contribute to an understudied driver—the role of funders—in order advance general knowledge of the science-society relationship as well as context-relevant insights about how to improve it. As future research on the topic of science funding program management develops, there is the opportunity for funding to be less of a common lament and more of a strategic driver, if strategically and efficiently employed, to implement beneficial changes throughout the science system.

Chapter 6. Conclusion

A decade ago, my first real job out of college involved coordinating an event that unexpectedly shaped the future of my career. New research on what makes science more usable for decision-making suggests what I witnessed back then may also be shaping the future of how we do science and apply it. In fact, it may also represent a key piece of the puzzle for how to innovate—and fund—solutions to our looming environmental and sustainability challenges.

The event brought together climate change scientists with staff from the some of the largest water utilities in the United States. This first-of-its-kind gathering aimed to integrate scientific and practical expertise to figure out how best to inform utility operations and capital investments in the face of climate change. At the time, it was becoming abundantly more clear that "stationarity was dead." That is, what had been considered normal from looking at past records of climate and hydrology could no longer serve as a guide for the future (Milly et al., 2008). To make sense of this, the event I helped convene enabled practitioners to convey their deep knowledge about their domain and problem sets, while researchers highlighted what was already known and what might be knowable through future research. In fits and starts, the participants were beginning to *co*-produce knowledge to help solve practical problems.

When looking across the science system today, particularly in the environmental and sustainability domain, we observe this practice of scientific knowledge co-production is in the midst of a growth spurt (see Figure 6-1). Fueling this surge is the expectation that more collaborative, inclusive, and de-siloed modes of producing and sharing knowledge will better enable society to tackle 21st century problems. Scientific research about information use and decision-making has recognized many factors that influence the way individuals, organizations, and societies act, or do not act, in response to scientific knowledge (Jasanoff & Wynne, 1998). Greater attention to these factors, which can be enabled through deliberate processes like co-production, have been shown to increase the likelihood that new scientific knowledge will be used to guide or inform actions. For example, recent experimental work on fishery management in Germany found that groups of resource managers who were interactively engaged by researchers (treatment group), rather than merely talked at through conventional lectures (control group), were more likely to understand and retain new knowledge as well as adopt more pro-environmental practices (Fujitani et al., 2017). Anticipation of these practical benefits, as well as the intrinsic benefits of more collaborative styles of research, are leading to a wider embrace of co-production by many researchers and scientific organizations (Lemos et al., 2018).

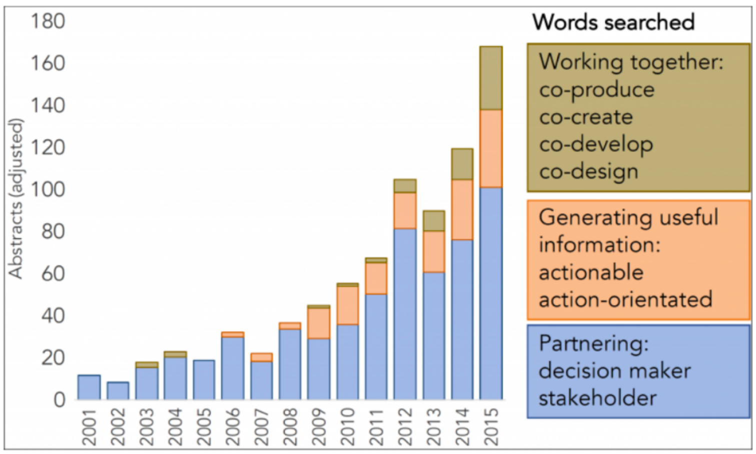


Figure 6-1.Word search of American Geophysical Union Fall Meeting abstracts. Terms searched indicate partnerships between scientists and decision-makers grew from 2001 through 2015 and suggest a growing interest in coproduction (Vano et al., 2017)

Of course, co-production is not cheap. The process of conducting research with various types of stakeholders, and investing the resources to reach out to them (physically or virtually) to build trusted relationships, necessarily requires additional time and resource commitments from all participants. Consequently, understanding how co-production can become a viable strategy at scale for addressing the mounting pace and scope of environmental challenges requires more methodical consideration of how to overcome these practical constraints.

One area of opportunity involves looking into the role of research funding organizations. As holders of the purse strings, funders have the potential to help cover the costs of co-production as well as incentivize research practices that lead to their expanded deployment and legitimization in the eyes of organizations, such as research institutes and universities. As funders also mobilize large volumes of scientific activities, they typically collect valuable data on processes, outputs, and outcomes along the way. Thus, funders can serve as key partners in research to create, maintain, and analyze datasets that can help to answer important questions about the drivers of actionable science. In turn, this knowledge, itself ideally co-produced, can inform adaptive management within funding programs that can aid their continuous improvement over time.

Funding knowledge co-production

In recent years, I have had the opportunity to study public science funding organizations in the United States and Europe. This research has explored how changes in the design of funding program can influence research practices, increase research utilization, and introduce changes to how scientists think about science that may affect the culture of knowledge creation more generally. One organizing question has been to understand whether funding program structures, and the incentives they wield, can shift notoriously stubborn research cultures. Even though funder influence over research might appear to be intuitive, the evidence about what funders can bring about through program design changes, or how precisely to wield such influence, is quite limited and inconclusive.

Another organizing question has been to look across many examples of efforts to fund and apply co-production to understand if expectations of the benefits of this practice related to knowledge use are warranted. Despite enthusiastic embrace of co-production, and perhaps a growing shift towards more collaborative research cultures underway for other reasons, there is quite little systematic evidence about what co-production produces across context and style of approach. Thus, further study of this phenomena is motivated by the need to help guide the implementation of co-production, rationalize how (much) to invest in this approach relative to other ways of doing research, and more fundamentally understand the drivers of knowledge use in decision-making.

A long-term, and still ongoing study, of one single program has already produced some intriguing results to help address these questions. The National Estuarine Research Reserve System, a program within U.S. National Oceanic and Atmospheric Administration, is unique in that over the last 20 years, program managers have periodically revamped the structure to encourage more interaction between their researcher grantees and the community of coastal resource managers and other practitioners they hope will utilize the research to manage coastal resources more sustainably (Trueblood et al., 2019). Using data from NERRS's natural experiment, my colleagues and I examined 120 reports and interviewed 40 past grantees and users. We investigated both how research practices changed during each distinctive generation of program design, as well as looked at whether research results were utilized.

What we found was that funding program incentives for researcher-practitioner interaction, including co-production, resulted in meaningful changes to research practice and longer-term changes in research cultures. Almost no grantees interacted with potential users at any level during the initial phases of the funding program evolution and few project reports demonstrated any more than cursory awareness of user contexts or management criteria that the research could inform. By later phases, when encouragement to co-produce research had been reinforced through requirements for the inclusion of collaborations specialists, nearly all researchers demonstrated some level of interaction with users, and many sustained it through more intensive forms over the entire course of the research process. We also found that interactive approaches to research can result in more benefits for society in the form of more evidence that research results are actually utilized to address complex sustainability and environmental challenges. Furthermore, of many factors considered to explain utilization, our statistical modelling found that interaction intensity was a significant factor in leading to use.

These findings are striking given the persistence of research cultures amid less successful prior attempts to affect change through funding program designs. For example, scholars studying reforms to incorporate the Broader Impacts criterion at the National Science Foundation have suggested these changes tended to reinforce, rather than readjust, longstanding cultures of researcher autonomy. The results of the NERRS experience also lend confidence to the aspirations of many researchers, funders, and practitioners who already believe that a more interactive, inclusive, and de-siloed science system will enable us to better tackle 21st century challenges.

However, results like these from one funding program's evolution would be more meaningful if they were part of a larger trend in Earth, environmental, and sustainability science funding. As a complement to the longitudinal analysis of the NERRS program, I have also examined many current funding programs across the United States and Europe. Analyzing funding program solicitations and conducting over 70 hours of interviews with public science funding program managers enabled me to explore whether other funding programs were changing in similar ways to NERRS, experimenting with other kinds of program design tweaks, or, alternatively, intentionally choosing to maintain the status quo. From this work, I found many examples of motivation—and innovation—to restructure the way in which science is expected to serve society. Funders across both continents reported increasing pressure and motivation to increase the amount of societal impact that follows from their sponsored research and are encouraging, or in some cases requiring, co-production as well as other strategies to help make this happen. Yet, this did not characterize all individuals or funding programs, and in fact what we found was not a clean shift from one funding style to another but rather the unfolding of numerous different funding styles, each presupposing a different relationship between science and society.

This research signals changes in the practice, and culture, of doing science. And it also sheds new light on the role of funders as an influential force in driving co-production as well as knowledge use. But there are outstanding practical and ethical issues that are still unresolved. For example, trusted relationships are a core pillar of why we think co-production can help increase the use of research in practice, but it is still not clear if or how this practice can be scaled to sufficiently respond to support the accelerating demands for action on environmental and sustainability issues. For example, the convening of water resource managers brought around 10 water utilities to the table together with scientists, yet in the United States alone there are more than 55,000 water utilities (Office of Water, 2008). Furthermore, as the practice of co-production expands, so do the risks that the process will become rote, with researchers paying 'lip service' to its principles and best practices in order to capitalize on incentives provided by funders or employers (Klenk et al., 2015). There are also many questions about equity, which range from consideration of how different participants of co-production are compensated for their contributions to whether the resulting application of knowledge for societal use leads to just outcomes in the world.

Next steps & recommendations

More work is needed to advance understanding about how science can serve society better, including the particular contribution of approaches like knowledge co-production. Encouragingly, there is a burgeoning community of social scientists and other researchers pursuing work on this area of inquiry, which we call the science of actionable knowledge (see forthcoming special issue in *Current Opinion in Environmental Sustainability* entitled, "Advancing Knowledge for Sustainability"). Here, scholars from fields of political science, decision science, anthropology, science and technology studies, and other domains apply the tools of social scientific inquiry to the study of science itself, but with an applied aim of helping researchers, practitioners, and institutions to make decisions at the science-practice interface that will help produce more beneficial outcomes on challenges like sustainability. While this may sound a bit "meta," this effort builds on the premise that the kind of systematic, rigorous methods of inquiry that science affords can help us to better understand science in the same way they help advance practice-relevant understanding of other complex social and nature phenomena. Thus, as scientists and users of science explore different ways of organizing science, we might have a better ability to guide decisions about science in the same way we hope science can support choices in other realms, like water or coastal resource management.

To support more widespread efforts toward this goal, I would like to offer several recommendations for moving forward.

1. Engage funders as research collaborators. One of the insights from my recent research has been to re-imagine the role of science funders. Rather than viewing funders as organizations that work at a distance from the activities and applications of research, I have come to view funders as potentially constructive partners that can interact with scientists and users to support actionable, or usable, science. Furthermore, beyond supporting co-production between researchers and users, science funders can contribute their expertise and their capacity to collect and track data, helping to co-produce new knowledge about the drivers and mechanisms of actionable science. This knowledge can provide an evidence base for funders to make changes to their own program as well as cultivate stronger practices for research-practice collaboration. Moving funders into this new role raises important questions about accountability, potential biases in funding allocations, and the importance of safeguarding intellectual freedom when pursuing research.

2. Clarify variables and mechanisms on both process and outcome. A recurring challenge throughout my research on co-production has been the persistent ambiguity in some of the most basic factors to understanding actionable science. Beneath a high-level aspiration to produce knowledge collaboratively and increase knowledge use, it can be difficult to characterize what knowledge use means or what kind of particular research approaches lead to different types of knowledge use. While structures for pursuing and understanding co-production (process) and impacts like knowledge use (outcome) must accommodate a diverse range of actors, contexts, and methods, a better means of characterizing the fundamentals would allow for more systematic and generalizable analyses. In turn, added clarification could help further a science of actionable knowledge by cultivating the evidence base more suitable for testing hypotheses, comparing results, and providing specific and tailored conclusions to science policy-makers, funders, and research organizations. For example, my research has identified that even grantees who deliberately employ co-production to generate usable knowledge have difficulty characterizing who the users were, who they aimed to work with, what kinds of uses happened, or how any form of broader outcome could be attributed to use. Developing versatile frameworks for systematically grappling with these difficult to characterize and predict factors could be piloted and potentially mainstreamed to support a more coherent and productive set of interactions between funders, researchers, and users of science.

3. Invest in program and project level evaluation. Throughout dozens of interviews with program managers, grantees, and intended users of research, I became increasingly surprised by the disconnect between the volume of resources and activities mobilized through their efforts and the paucity of investment in their evaluation. Even in instances where evaluation was pursued, it sometimes occurred out of sequence with decisions about future program design, rendering any insights less valuable for guiding future innovation. I became further concerned with this gap when realizing in my own research the significant gains in understanding that can be made when undertaking systematic analysis of the influence and outcomes funding program activities. Although my efforts to learn from the NERRS example by looking backward were painstaking—more like archeology than accounting—and even though not all evaluation approaches may yield insights that outweigh their cost or burden, future investments, particularly by funders, could identify more efficient and effective pathways to evaluation. For example, NERRS is now incorporating a short pre- and post-survey of end users for their funded projects in order to quickly learn about changes in the user context over the course of a project, alleviating the burden on grantees to speculate or collect additional data for their own reporting. Given the volume of projects mobilized by funders every year through competitions, not learning as much as possible from the processes undertaken and results achieved by them is an enormous missed opportunity. Ideas for how to begin in this direction include:

- Make efforts to track well-defined, and ideally commonly utilized, variables of both process and outcome. For example, if use is the object of evaluation, be clear about what use entails and attempt to correspond this definition with others
- Inform evaluation through the triangulation of perspectives from grantees, funders, and users. For example, consider soliciting information directly from users in addition to grantees during both ex ante and ex post review procedures.
- Coordinate evaluation efforts to be supportive (rather than superfluous) to the timeline of decision-making by program management about program design changes. For example, designing new funding solicitations prior to the conclusion of evaluation from prior years of performance limits the usability of those evaluation investments.
- To alleviate burden on grantees, funders, and users, identify ways to substitute new reporting and evaluation procedures rather than add new, supplementary requirements.

Final thoughts

Around the same time as I helped to bring water managers and scientists together, I was also captivated by a question that seems more relevant today than ever before. Posed by the late climate scientist Stephen H. Schneider, the question is: *can democracy survive complexity*? In a world of seemingly constant, often disruptive, and likely transformative change, this question prompts us to wonder how our fundamental political and social structures will adapt, or whether they will ultimately endure. On the surface, past advances in scientific understanding provide good reason for optimism that new breakthroughs will keep pace with mounting challenges and in the process help to guide decision-makers at all levels. However, persistent gaps between science and decision-making, coincident with fissures growing within our social and political institutions, are cause for serious concern and signal that perhaps more scientific knowledge will not, alone, furnish the solutions required by mounting disruption due to global change. Fortunately, it increasingly appears that the approaches to science more likely to help—collaborative, inclusive, de-siloed—reflect a set of broader strategies that society as a whole may need to adopt in order better solve our collective sustainability and environmental problems. Continuing to grow in our understanding about how to pursue these types of strategies better, as well as faster, may be our best shot for a safe, and just, future for humanity.

Appendix

A-1 Complete codebook for documentary analysis of final reports (Chapter 2)

Table A-1 Complete codebook used for documentary analysis

Coding Group	Coding Options	Coding Criteria	Ref.	CSV Variable Name
1. Research Aims	a. new science/data	a. Project seeks, as a primary aim, to produce new scientific understanding or data	(Meadow et al., 2015)	1.1
	b. new technology or method	b. Project seeks, as a primary aim, to develop prototype for new technology/method/practice for use by management		1.3
	c. dissemination	c. Project seeks, as a primary aim, to disseminate knowledge to communities of practice (as a primary goal)		1.2
	d. testing in applied settings	d. Project seeks, as a primary aim, to test applicability of new knowledge/technology/ method in user/management contexts (not field research).		1.4
	e. learning from users	e. Project seeks, as a primary aim, to learn from information/technology users to guide applied research		1.5
2. Origins	**Research question**		(Meadow et al., 2015)	
	a. Not specified	a. Origin of research question not identified		5.0a
	b. From researchers only	b. Researchers develop research question		5.1
	c. From users only	c. End users develop research question		5.3
	d. From combination	d. Combination of researchers and end users develop research question		5.5
	Research design			
	a. Not specified	a. Origin of research not identified		5.0b
	b. From researchers only	b. Researchers develop research design/tech. development		5.2
	c. From users only	c. End users develop research design		5.4
	d. From combination	d. Combination of researchers and end users develop research design		5.6

3. Relevance	**Decision/management *context***		(Moss, 2015)	
	a. None identified	a. No specific decision/management context identified		2.0a
	b. General	b. Identification of general decision/management *context* for information/technology use		2.1
	c. Specific	c. Identification of specific decision/management *context* for information/technology use		2.3
	Decision/management *criteria*			
	a. None identified	a. No specific decision/management criteria identified		2.0b
	b. General	b. Identification of general decision/management *criteria* for information/technology use		2.2
	c. Specific	c. Identification of specific *criteria* of information to existing decision/management		2.4
4. Dissemination	a. None	a. No description of information/ knowledge/technology dissemination	(Klenk et al., 2015; Meadow et al., 2015)	10.0
	b. Academic	b. Information/knowledge/technology disseminated through typical research outlets (e.g. academic conference proceedings, peer-reviewed publications, etc.)		10.1
	c. Loading-dock to practice	c. Information/knowledge/technology passively disseminated to communities of practice, such as made available on researcher website (i.e. Loading Dock approach)		10.2
	d. Active to practice	d. Information/knowledge/technology actively disseminated to communities of practice		10.3
	e. Dissemination co-designed	e. Dissemination strategy co-designed and implemented with end users		10.4
5. Intensity of interaction	a. None (described)	a. No interaction identified	(Amara, Ouimet, & Landry, 2004; Klenk et al., 2015; Michaels, 2009)	7.0
	b. Linking	b. Targeted dissemination of knowledge to inform decision-making/management (Linking)		7.1
	c. Match-making	c. Diverse types of knowledge producers are connected with users to frame research questions and interpret results (Match-Making)		7.2
	d. Collaborating	d. Knowledge users are active throughout the process, including articulation of		7.3

	e. Coproducing	research questions, design of projects, collection and analysis of data, and production of outputs (Collaborating) e. Users are empowered and have capacity to critically assess and (co-)lead project.		7.4
6. Use ***(coded only by 1 coder)***	a. Evidence of use i. Instrumental ii. Conceptual b. Indeterminate c. Evidence for non-use	a. Demonstrable evidence of use of research outcomes i. direct use for decision-making and management actions (i.e. "Instrumental") ii. indirect use to inform priorities, agendas, and awareness (i.e. "Conceptual") b. Use was either not describe or it was anticipated without adequate evidence of eventual outcome c. Specific evidence of inability for use provided	(Pelz, 1978)	Use
7. Directionality	a. None (described) b. Unidirectional c. Unidirectional w/ some consultation d. Bi-directional	a. No flow of information to end users described b. Unidirectional (i.e. From knowledge/technology producers to knowledge/technology users) c. Unidirectional but with occasional consultation (i.e. Knowledge producers consult knowledge users) d. Bi-directional (i.e. Knowledge producers work with knowledge users to produce, understand, and apply knowledge in practice/decision-making)		4.0 4.1 4.2 4.3
8. User involvement	a. None (described) b. Primarily passive participant c. Participate in specific stages d. Continuously involved	a. Non-existent b. Primarily as passive recipient of new knowledge or technology c. Participating in specific stages only d. Continuous involvement		8.0 8.1 8.2 8.3

9. User readiness	a. None (described)	a. No discernable reference to user readiness/ or explicit mention of lack of readiness.	(Bechhofer et al., 2001)	3.0
	b. Initial stages	b. Project indicated that users were only at initial stages of readiness to utilize knowledge/technology produced (i.e. planned use or early stages of initial use)		3.1
	c. Adding value	c. Research produced is adding (or very likely to) add value to existing practitioner knowledge (i.e. user readiness such that new knowledge complements/builds upon existing knowledge/practice)		3.3
10. Research readiness	a. None described	a. No discernable reference to the readiness of available knowledge/technology to meet user needs		3X.0
	b. Not yet ready	b. Knowledge/technology not yet available or ready to meet user needs, even after project completion (i.e. gaps still exist)		3X.1
	c. Partial/potential	c. Knowledge/technology potentially available to end users, may be tested at least partially in real world context, but still not indicated as fully usable form, as of project completion		3X.2
	d. Available for or in use	d. Knowledge/technology available (e.g. concluded, patented, published, or commercialized) and/or supplied in usable form as of project completion (regardless of user readiness or desire) [e.g. disseminated to communities of practice, etc.]		3X.3

A-2 Semi-structured interview guide (Chapters 2 & 3)

Potential questions to ask of funded projects, stakeholder participants, designated end users connected to projects funded by the National Estuarine Research Reserve System (1998-2014).

<u>Interview will proceed in a semi-structured manner.</u>

Potential interviewees:
- Project Team Leader or other (incl. reserves)
- End user (as designated, incl. reserves, with slight modifications to questions as appropriate)
- Other stakeholder (if no end user ID'd, with slight modifications to questions as appropriate)

Interview START:
- Warm welcome
- Thank you for agreeing to be interviewed today.

Informed consent
- There are some things I have to cover at the outset in order to properly obtain your participation in this

study.
  - o FIRST: I'm going to ask questions about your experience conducting research and the application of that research into practice.
  - o SECOND: I'd like to be able to record this interview to produce a transcript to be used only by our research team for reference and analysis. While I plan to utilize the insights you share with me to complete this study, anything you share with me will not be attributed to you personally and any potentially identifying information in what you share will be removed before sharing more broadly.
  - o Is it okay with you to proceed with this interview and to record it? Or do you have any questions for me before we proceed?
- If YES, say we'll put on hold for a second and be back momentarily
- If NO, ask if there are any specific questions or concerns about doing the interview. And then if concern about recording persists, offer to continue the interview with only notetaking by
  ---
- Thanks, ____, for agreeing to participate. We're now on a recorded line. We're hoping to talk to you about the project(s), ____. Just to let you know, we've had the opportunity to read the final report your team submitted on behalf of the project. We are now interested to hear from you what you recall about the project since its completion as well as some specific insights you might have about how research becomes utilized in practice.

Opening question:
- As a start, I want to hear any highlights you remember about the project. I realize that these activities took place [quite] some time ago, so don't worry if you can't remember everything. Please just tell me what you can remember that stands out as memorable or significant. [ACTIVITIES/OUTCOMES/IMPACT]
  - o *If recollection is limited, remind interviewee of few keywords from abstract, end date of project, other collaborators, and other tidbits from abstract as needed.*
  - o PROBE: How did the design of the project and its objectives come together? Who was involved? [ORIGINS]
  - o PROBE: What do you recall were some of the main achievements of the project? [OUTCOMES]
  - o PROBE: Is there anything noteworthy that has occurred in relation to the project since its completion? [OUTCOMES]

Note: Most of the interview may proceed organically from this opening question. See following questions for follow up in key areas of research interest.

Follow on questions
- What were the coastal/estuarine management issues this project was seeking to address? [RELEVANCE/CONTEXT]
  - o PROBE: Were there specific needs resource managers or decision-makers that you were trying to provide for?
    - ▪ Or, were there other types of users?
  - o PROBE: From your position, how did you come to what decision-makers or others needed? [INTERPLAY]
  - o PROBE: Throughout the project, did your understanding about their needs change over time? If so, how? [INTERPLAY]
  - o PROBE: What were some of the aspects of the project that enabled you to better understand their needs? [INTERACTION/INTERPLAY]
- [If nothing has been volunteered up to this point about interaction] During the project, to what extend did you interact with decision-makers, resource managers, or other potential users? [INTERACTION]
  - o PROBE: What was the nature of that interaction? What forms? What was communication

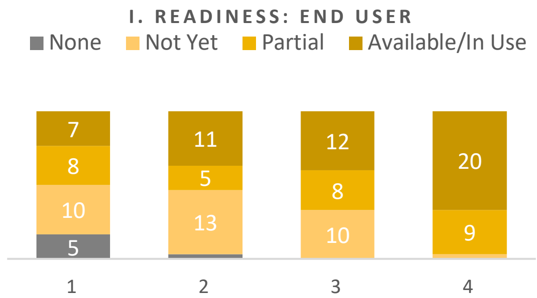
like? [INTERACTION/COMMUNICATION/REPRESENTATION]
    - Was the input open ended or focused?
    - PROBE: How often do you recall interacting? [INTERACTION]
    - PROBE: How did the interaction influence the project and its outcomes?
    - PROBE: clarify users versus advisors/stakeholders
- Either during or after the project, do you know whether outputs from the project were utilized by practitioners, resource managers, or decision-makers?
    - PROBE [If no use]: To what do you attribute this? Was this not part of the original intent of the project, or were there barriers to the ability for this to become usable?
        - In your opinion was the research ready to be utilized?
        - Were end users prepared to be able to utilize your research?
    - PROBE [if use]:
        - Could you describe the way in which this new knowledge (or technology) was utilized)
        - How have you come to understand this?
        - To what do you attribute the success in uptake?
        - PROBE (as appropriate): Could this kind of uptake occurred without the participation of [end user, stakeholder, etc.]
            - PROBE: What specifically about their participation helped aid in the application?
- What outcomes in the coastal/estuarine environmental resulted from this?
- Do you think that funding source for this project (e.g., NERRS – CICEET or NSC) had any influence over the approach you pursued?

[Opportunity for additional questions]

- Getting toward the conclusion of this interview… Is there anything you know now (about applied or collaborative research) that you wish you knew when you were involved with this project?
    - PROBE: Did you ever find that the interaction or collaboration was unnecessary, too much, or a hindrance?
- Is there anything else you would like to share about your recollections of the project?
- Is there anyone you could recommend that might fit into the category of an user that we could talk to get their perspective? This could be someone that was actively involved in the project, or if that's not possible, someone that came to utilize results from the project afterwards…

A-3 Additional coding results (Chapter 2)

Figure A-0-1 Additional coding results



A-4 Additional analysis (Chapter 2)

Table A-2 Modelling results for coding relative to Generation 1. "Loading Dock"

Coded variable	Model type	Generation 2		Generation 3		Generation 4	
		t/z-value	*Odds Ratio*	*t/z-value*	*Odds Ratio*	*t/z-value*	*Odds Ratio*
Aim: New Science/Data	L	-2.68***	0.18	-1.33***	0.27	-0.26**	0.77
Aim: New Technology	L	1.83*	2.75	2.63***	5.00	-1.30	0.50
Origin: Research Question	O	1.11	3.42	1.67*	7.18	3.65***	62.64
Origin: Research Design	O	0.61	2.22	1.09	4.04	3.89***	101.98
Relevance: Context	O	2.32	1.90	1.95*	2.65	3.97***	9.09
Relevance: Criteria	O	0.98	1.62	1.46	2.04	2.71*	2.24
Dissemination: Academic	L	-0.31	0.82	-1.67*	0.38	-1.67	0.38
Dissemination: Practice	L	1.29	1.96	0.52	1.31	3.36***	37.92
Interaction: Intensity	O	1.20	2.11	2.68*	5.11	6.60***	503.48

p < 0.1 - *, <.05 - **, <.01 ***. *L – logistic regression (binomial), O – ordinal logistic regression. All results relative to Generation 1. See A-4 for modelling results with other generations as reference level.*

Table A-3 Modelling results for coding relative to Generation 2. "Technology Transfer"

Coded variable	Model type	Generation 1			Generation 3			Generation 4		
		t/z	*OR*	*95%CI*	*t/z*	*OR*	*95%CI*	*t/z*	*OR*	*95%CI*
Aim: New Science/Data	L	2.68***	5.69	(1.71, 22.91)	0.78	1.51	(0.54, 4.31)	2.41**	4.38	(1.39, 15.77)
Aim: New Technology	L	-1.84*	0.36	(0.12, 1.05)	0.93	1.82	(0.53, 6.80)	-3.01***	0.18	(0.06, 0.53)
Origin: Research Question	O	-1.01	0.29	(0.01, 2.61)	0.86	2.10	(0.41, 13.2)	3.76***	18.31	(4.66, 104.40)
Origin: Research Design	O	-0.61	0.45	(0.02, 5.58)	0.55	1.82	(0.22, 19.64)	4.1***	45.79	(9.28, 423.82)
Relevance: Context	O	-1.32	0.53	(0.20,0.52)	0.66*	1.39	(0.52,3.78)	-2.82***	0.21	(0.07, 0.60)
Relevance: Criteria	O	-0.98	0.62	(0.23, 1.62)	0.46	1.26	(0.48, 3.30)	0.68	1.38	(0.54, 3.52)
Dissemination: Academic	L	0.31	1.22	(0.35, 4.31)	-1.38	0.46	(0.14, 1.37)	-1.38	0.46	(0.14, 1.37)
Dissemination: Practice	L	-1.29	0.51	(0.18, 1.41)	-0.78	0.67	(0.23, 1.85)	2.73***	19.33	(3.40, 367.45)
Interaction: Intensity	O									

$p < 0.1$ - *, <.05 - **, <.01 ***. *L – logistic regression (binomial), O – ordinal logistic regression. All results relative to Generation 1.*

Table A-4 Modelling results for coding relative to Generation 3. "Knowledge Systems"

Coded variable	Model type	Generation 1			Generation 2			Generation 4		
		t/z	*OR*	*95%CI*	*t/z*	*OR*	*95%CI*	*t/z*	*OR*	*95%CI*
Aim: New Science/Data	L	2.01**	3.76	(1.10, 15.28)	-0.78	0.66	(0.23, 1.85)	1.72	2.89	(0.89, 10.51)
Aim: New Technology	L	-2.63***	0.20	(0.06, 0.63)	-0.93	0.55	(0.16, 1.90)	-3.69	0.10	(0.03, 0.32)
Origin: Research Question	O	-1.66**	0.14	(0.01, 1.05)	-0.86	0.48	(0.76, 2.47)	3.37***	8.73	(2.66, 34.32)
Origin: Research Design	O	-1.09	0.35	(0.01, 2.5)	-0.55	0.55	(0.05, 4.60)	4.06***	25.23	(6.2, 151.60)
Relevance: Context	O	-1.95*	0.38	(0.14,0.99)	-0.66	0.72	(0.26,1.92)	2.20**	3.43	(1.17, 10.81)
Relevance: Criteria	O	-1.46	0.49	(0.19, 1.27)	-0.46	0.79	(0.30, 2.08)	0.20	1.10	(0.44, 2.74)
Dissemination: Academic	L	1.67*	2.67	(0.86, 8.95)	1.38	2.19	(0.73, 6.98)	0.00	1.00	(0.35, 2.83)
Dissemination: Practice	L	-0.52	0.76	(0.27, 2.11)	0.78	1.50	(0.54, 4.23)	3.12***	29.00	(5.13, 550.01)
Interaction: Intensity	O									

Table A-5 Modelling results for coding relative to Generation 4. "Collaborative Science"

Coded variable	Model type	Generation 1 *t/z*	*OR*	*95%CI*	Generation 2 *t/z*	*OR*	*95%CI*	Generation 3 *t/z*	*OR*	*95%CI*
Aim: New Science/Data	L	0.36	1.30	(0.31, 5.78)	0.36**	1.30	(0.31, 5.78)	-1.72*	0.35	(0.10, 1.12)
Aim: New Technology	L	1.30	2.00	(0.71, 5.81)	3.01***	5.50	(1.88, 17.54)	3.69***	10.00	(3.13, 37.28)
Origin: Research Question	O	-3.65***	0.02	(0.00, 0.10)	-3.76***	0.05	(0.01, 0.21)	-3.37***	0.11	(0.3, 0.38)
Origin: Research Design	O	-3.89***	0.01	(0.00, 0.07)	-4.07***	0.02	(0.00, 0.12)	-4.06***	0.04	(0.01, 0.16)
Relevance: Context	O	-3.97***	0.11	(0.04, 0.31)	-2.82***	0.21	(0.07, 0.60)	-2.19**	0.29	(0.09, 0.86)
Relevance: Criteria	O	-1.71*	0.45	(0.18, 1.12)	-0.68	0.72	(0.28, 1.84)	-0.20	0.91	(0.36, 2.27)
Dissemination: Academic	L	1.67*	2.67	(0.86, 8.95)	1.38	2.19	(0.73, 6.98)	0.00	1.00	(0.35, 2.83)
Dissemination: Practice	L	-3.36***	0.03	(0.00, 1.5)	-2.73***	0.05	(0.00, 0.30)	-3.12***	0.03	(0.00, 0.19)
Interaction: Intensity	O									

A-5 Complete coding data (.csv file)

See attachment named: "NERRS_codes.csv"

A-6 Interview questionnaire (Chapter 5)

1. Can you help me understand more about the kind of work you do? What are you working on this summer? What are your general responsibilities?
2. How long have you worked as a [program manager]?
3. Can you tell me about the ____ [program]? What is its overarching aim?
4. When it comes to _[program]_, how involved are you in the writing or design of funding solicitations (or program descriptions, etc)? Δ Do you write them yourself? How do they get approved? What limitations are there on the ability to change them?
5. Can you recall how the most recent solicitation was developed?
6. What is your involvement in other management aspects, e.g. selection or evaluation?
7. Did it change from before? How? How often does it change?
8. What was the thinking behind component X, Y, and Z (see list of program specific questions)? Is that normal? How did that develop? What was the motivation? How do you think it influenced the outcomes?
9. Have you observed any general trends/changes in how funding programs are structured?
10. How much flexibility do you personally have in shaping the RFP?
11. To what extent do you think the RFP shaping what kinds of research gets funded? How?
12. Are there things that you would like to change about the program (in any way)? Why?
13. What kinds of things constrain your ability to make changes?
14. Are you involved in management for any other funding programs?

15. How do you think the kind of research you fund leads to societal benefits?
16. What kinds of societal benefits do you believe occur through research you fund?
17. Do you ever feel that the research you fund could achieve more societal benefit?
18. Do you think that the way science is funded has the potential to change the way science makes an impact on society?
19. Are there any particular changes you imagine would improve the societal benefits?
20. How much do you think the RFP influences the societal benefits of research?
21. How much do you think other aspects of program management influence?
22. Does people you work with generally agree with your views about societal impact?
23. What kinds of resistance within the agency? By broader community?
24. Has your view about the role funders play in shaping science and societal impact changed in the course of your career?
25. Are there other strategies or tactics that you think are or would be appropriate?
26. Going back to the funding program you manage, who do you work with internally or externally to shape the design of the solicitation (aside from subordinates or assistants)?
27. Based on the kinds of questions I've asked you, do you have anyone in mind that you would recommend I speak to?

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