Hearing on The Science of Science and Innovation Policy
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According to the National Science Foundation (NSF), the Science of Science & Innovation Policy (SciSIP) program "supports research designed to advance the scientific basis of science and innovation policy[1]. The program is an important and bold attempt to build a strong intellectual foundation for science and technology policy making regarding the laws and rules that shape the institutional environment in which scientific research and innovation takes place. It does so by adopting recently developed, leading-edge methodological approaches based on both large scale empirical data analyses and complementary qualitative analyses. The explicit goals of the program are to fund research that "develops, improves and expands models, analytical tools, data and metrics that can be applied in the science policy decision making process". From *my* perspective as a SciSIP scholar, I conceptualize the SciSIP agenda as the systematic, evidence-based and causal analysis of the impact of policy interventions on the rate, direction and impact of scientific knowledge production and innovation. If successful in research and in coupling to policy decisions then this agenda will enable Federal and state policymakers, as well as others engaged in shaping the production and translation of scientific knowledge (including scientists themselves, universities, Foundations and scientific communities), to design more effective policies and practices that ensure that investments in science and innovation have rapid and extensive scientific, social, and economic impact.

In this testimony I lay out my personal views of the SciSIP program from the perspective of an NSF-SciSIP scholar (and grant recipient), and as a Faculty member in a leading School of Management who engages routinely with scientists concerned with the impact of their research, policy students as well as MBA students and executives hoping to work effectively at the academic-commercial interface.

In what follows I examine some recent breakthroughs that have enabled SciSIP research, outline some of the key research emerging from SciSIP to date and critical gaps. I then turn my attention to what I observe as the need for greater community building and finally, the potential for a significant educational initiative.

[1] Accessed from http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=501084&org=sbe 9/16/2010.

The notion that there can be a "science" of science and innovation policy is relatively recent (Marburger 2005). There is a long and distinguished traditional of science policy research nonetheless, the current focus on measuring the causal influence of science and innovation policy levers at different levels (national policy, agency interventions as well as community and lab-level actions) can be linked to advances in economics and related fields in the early 1990s. During this period, leading economic historians including Paul David, Joel Mokyr and Nathan Rosenberg developed critical conceptual breakthroughs in understanding the economics of science and innovation as grounded both in institutions (policy levers) but also in the micro-level behaviors and incentives of scientists and engineers themselves. Building on economics as well as the sociology of science, they came to view Science as a distinctive institution in several ways: as a knowledge production system, as an input into technological innovation, and as a reward system.

The empirical promise of this conceptual agenda was taken forward by a group of economists and sociologists who aimed to evaluate the impact of public policies on research behavior, research outputs, and associated economic outcomes (Marburger, 2005; Jaffe, 2006). In following this agenda, scholars confront a number of key challenges. In particular is it possible to separate the influence of a particular policy or institution from the underlying nature of the scientific knowledge that is being developed? To put it more simply, in the policy "whodunit" it is often hard to say whether it is the policy that had the effect of speeding up scientific progress in a particular area or a chance in our understanding of a scientific problem. Without a parallel universe for policy experiments, when one observes the production or diffusion of a piece of knowledge within a given policy environment, one cannot directly observe the counterfactual production and diffusion of that knowledge had it been produced and diffused under alternative policy conditions. To resolve these challenges, SciSIP scholars have combined methodological advances in program evaluation- particularly a "natural experiments" approach - with novel data techniques. The experiments-based approach (with which the committee is likely familiar from its work on education) relies upon methods pioneered in public finance and program evaluation (Meyer, 1995; Bertrand, Duflo, and Mullainathan, 2004; Angrist and Pischke, 2008). To complement these methods, SciSIP scholars have made extensive use of novel datasets including data on publications, patents and most recently citations. This approach uses these "documents" as the core objects of analysis, assuming that they represent "pieces of scientific knowledge," and citation analysis to investigate the impact of institutions on the cumulativeness of discovery and innovation (Garfield, 1955, De Solla Price, 1970; Jaffe, et al, 1993; Griliches, 1990, 1998). When placed within a framework to evaluate science and innovation policy, these elements constitute a robust approach to analyzing and tracking the causal impact of public policies on science and innovation inputs and outputs.

The power of the emerging SciSIP agenda is to incorporate these novel approaches and therefore move beyond description and observation of science at work or particular policies towards the more systematic analysis of particular institutional interventions. Thus pioneering SciSIP research typically combines three elements:

i) Providing clear theoretical foundations for understanding the ways in which institutional change (at any level) might influence the behavior of scientists and therefore the rate and direction of their knowledge production.

ii) Building careful empirical designs that enable causal analysis, and undertaking these empirical studies using systematic data gathering methods at different levels (including quantitative data but also including qualitative studies).

iii) Grounding the analysis in a deep understanding of the phenomenon – the details of the particular policy changes or organizational choices as well as the ways in which these shape scientists daily life.

As a contributor to the broader SciSIP agenda and approach, my research in the past few years has focused on the conflicts and compromises shaping the boundary between academic science and the commercial world -- especially the impact of intellectual property (IP) rights and IP licensing strategies over basic scientific research in areas as diverse at human genetics, stem cells and cancer biology. More recently I have expanded my research to examine the community and organizational-level interventions that scientists can make including understanding how research quality is governed (through retractions) and how projects are selected and evaluated). In my own work, I have found that my training as a scientist provides aids in the third element of the SciSIP approach but my work is strongly based on the theories and methods of economics and sociology of science and therefore links the three aspects outlined above.

A research project of mine recently completed with a series of co-authors illustrates the SciSIP approach to the analysis of science policy. It was designed to adjudicate one policy element of the institutional complex - the impact of intellectual property rights on research tools (and the licenses that shape access to such tools) on scientific productivity and diversity. Rather than theorizing broadly, it focuses specifically on one controversial episode in the genetics community initiated by the discovery, patenting and then exclusive licensing of mouse genetics technology (the Oncomouse approach and the related Cre-lox approach) and the subsequent licensing agreement made among DuPont, the Jackson Laboratories and the National Institutes of Health to enable greater access to these key research tools.

In <u>The Oncomouse that Roared</u> (Murray 2010), I take a qualitative approach to the question of whether and how the Oncomouse patent influenced the scientific community. Rather than compare the mouse genetics community to another scientific field (which may have any number of inherent differences), I compare the periods before and after the Oncomouse patent was granted and licensed. For 3-4 years, with no intellectual property rights yet granted the mice were subject only to the informal norms that characterize a competitive, but collegial, scientific community. After the grant of the patent, DuPont (exclusive licensee) strongly enforced its property rights on scientists. Through detailed interviews and documentary analysis comparing the pre- and post- patent period, I follow the SciSIP approach and closely analyzed the impact of the Oncomouse patent on mouse geneticists. I find that some scientists reluctantly acquiesced, dealing with complex contracts. Others defied DuPont, sharing mice informally in the face of opposition from their universities. Behind the scenes other more complex changes were also taking place as scientists sought to reshape the role patents in their scientific life. This is reflective of broader changes in the scientific community in the face of higher levels of commercial interest and engagement and the resistance to the encroachment of high-powered commercial interests. Such a grounded perspective highlights the importance of understanding how scientists respond to policy interventions and has a number of policy implications. However it also raises a more SciSIP-oriented question about the causal impact of the compromise (when the NIH persuaded DuPont to sign a Memorandum of Understanding making Oncomice open for experimentation) on the level and type of research using these genetically modified mice i.e. do such policy interventions shape the rate and direction of science.

I examine the causal impact of these shifts to greater openness in "Of Mice and Academics" (Murray et al. 2010). The "dependent variable" in this paper is the level and type of scientific research publications that use genetically engineered mice in each year from 1990 until 2006– based on a dataset of over 20,000 publications that are coded by their level of basicness, the rating of the journal in which they are published, the rank of the school affiliations of the authors etc. The "independent variable" is the timing of the policy shift in the openness of particular types of transgenic mice (Onco mice and Cre-lox mice). To aid in the interpretation of the data we also include a control group of papers that build on mice never influenced by intellectual property rules. A central idea of this research design is that while research discoveries (such as engineered mice) are developed at a given point in time, their use by subsequent researchers takes place over time. This insight motivates a differences-in-differences approach to the analysis of follow-on scientific research: If the policy environment governing the incentives and/or ability to build on published discoveries changes over time (and affects only some discoveries but not others), it is possible to identify the impact of the policy change by examining how the pattern of follow-on research (captured in published articles) changes after the policy intervention. In other words, policy changes that impact one group of articles and not another can constitute a natural experiment. This paper exemplifies the SciSIP approach by linking (microeconomic) theory about the way researchers respond to openness, with data/empirics that allow for causal analysis, and a sufficiently detailed understanding of the policies and practices of scientists to enable appropriate research design. We find that the NIH MoU did indeed increase not only the level of research using these mice but also spurred a greater diversity of researchers to move into the field, follow novel paths and take new approaches.

Taken together these two papers address questions of how institutional and organizational changes shape the rate and direction of scientific knowledge. They follow the three key elements of the SciSIP approach by carefully and precisely focusing on the phenomenon at hand, using that detailed understanding to link theories of scientists' behavior to careful data, and building empirical strategies in a way that enables causal analysis, normative conclusions and theoretical contributions.

ASSESSING THE GAPS IN SciSIP KNOWLEDGE

As outlined above, the SciSIP agenda presents far reaching research opportunities for scholars whose goal is to contribute to the social sciences, to our understanding of science and innovation in the economy and to have policy impact. A number of significant gaps in the current state of knowledge remain and can be usefully considered around the organizing framework laid out below. This describes SciSIP research according to the level of analysis at which the policy interventions are taking place: national rules and regulations, agency-level interventions, community norms and practices and organizational actions. I then propose three cross-cutting questions that apply to each level (see below). To illustrate this perspective and the gaps it reveals, I first describe research on high level rules and regulations then move to more micro-level analysis of organizational interventions.

- **National rules and regulations**: This includes research on the effectiveness of national rules and regulations on the rate and direction of scientific progress. A major area of focus includes research on the influence of the Bayh-Dole Act on university researchers (Owen-Smith and Powell 2003). In my own recent research, we have examined the impact of US regulations with regards to the funding of research in the area of human embryonic stem cells (Furman, Murray and Stern 2010). *Gaps at this level of analysis remain with regards to the role of international rules and regulations on science in the United States, and the ability of U.S. researchers to remain highly competitive and at the knowledge frontier in the light of growing global spending on scientific research. In addition it would be valuable to understand how the particular funding levels, structure and incentives of university systems in different countries impact downstream outcomes, such as scientific production, firm founding, and health & welfare, and how they contour the impact of government policies such as those related to intellectual property rights.*

- **Agency or University-level rules and norms**: Funding agencies, especially the Federal government, have a variety of opportunities to shape the rate and direction of scientific progress. Both areas have up to now been poorly understood. Recent work funded by SciSIP has made significant progress along these two dimensions but gaps remain. *In particular the influence of non-Federal funding sources particularly corporate funding and the growing foundation funding is poorly documented and understood.*
    - **Shaping the Direction of Research:** Funding agencies, as they select among research projects and shape the expectations and controls they place on researchers have a variety of opportunities to influence knowledge production. This has often been thought of as a black-box with the scientific community utilizing the peer review system as the best mechanism to self-regulate and shape direction. Pioneering analysis by my MIT colleagues shows that exceptional scientists are much more likely to produce innovative breakthrough science when using long-term grants that allow them exceptional freedom in the lab (Azoulay et al, 2010)[2]. This study raises the question of how researchers are encouraged to move into new and emerging research areas, and how to encourage ideas at the high-quality high-risk tail of the distribution.

[2] They do this by comparing the research profiles of similar biologists some of whom receive more open ended long-term funding from Howard Hughes while others receive more traditional RO1-style grants from the NIH.

We must encourage more research to understand the impact of funding choices and funding incentives on the type of research outcomes. This agenda could also benefit from the analysis of scientists outside the U.S. in settings where different types of incentive systems exist. In line with recent interest in Challenges (prizes) as an alternative incentive mechanism, we should also extend this analysis to include other funding mechanisms or reward systems.

- **Shaping the Disclosure and Sharing of Knowledge and Materials:** Funding agencies have an opportunity to shape the rate and effectiveness with which knowledge that is generated as a result of grant-making is shared among scientists and is diffused into the economy along productive routes. Among the most important and controversial rules shaping such impact of scientific research are the rules around intellectual property rights. This has been the topic of vigorous debate particularly with regards to the increasing levels of patenting within the scientific community. This is the research arena in which SciSIP researchers have made one of the greatest contributions, with their research informing policy discussions at the National Academies of Science, within the National Institutes of Health (NIH) and elsewhere. In particular, research has explored the impact of patenting on the rate at which that research is diffused within the scientific community and on the rate at which commercial or socially-beneficial products are developed (Murray and Stern 2007; Huang and Murray 2009; Walsh et al. 2003, 2005). *Extensive research documents the impact of IP, licensing and material sharing practices on scientists, but gaps in our knowledge exist with regards to the impact of these policies on both scientific knowledge production and economic impact (few studies examine both with Williams (2010) a notable exception). We also have a less systematic understanding of how to design the "intellectual commons" in an efficient and effective manner so as to promote and rapid follow-on research and commercialization. There is also a significant opportunity to extend these studies beyond the study of life scientists to explore differences across research communities in a range of disciplines such as chemistry, computer science, materials science etc.*

- **Community level activities**: The policies and practices that emerge from the scientific community also play a critical role in scientific progress and impact. Thanks to more systematic analysis of resource-sharing arrangements both informally (see Hauessler et al. 2009; Waltsh et al., 2005) and through formal mechanisms such as Biological Resource Centers, there is definitive evidence that investments in community-based infrastructure such as materials repositories and data repositories have a significant positive impact on the rate of scientific progress by enabling access, certification and sharing (Furman and Stern 2010). More recent analysis of the self-governance of scientific communities through the system of retractions has also pointed out the role of the community as a crucial analytic lens (Furman and Murray 2009). In another stream of research grounded in organizational theory and sociology, scholars have examined whether and how different community structures emerge in order to undertake the complex task of horizontal collaboration (e.g. Powell et al. 2004, O'Mahony and Bechky 2008) and collective work (Ferraro and O'Mahony forthcoming).

At this level of analysis, critical questions remain unanswered: how are scientific communities formed? How do they coalesce around new research areas and what role might policy-makers play in such community formation? For example do mechanisms such as those used in DARPA enable community building and how does this shape the long run effectiveness of scientific communities?

- **Organizational Interventions**: Scientific research is an activity increasingly undertaken by collections of scientists organized into teams, networks, collaborations and networks. Recent scholarship highlighted the potential for significant productivity benefits of specific organizational choices (Cummings and Keisler 2005, 2007, Wutchy et al. 2007, Jones et al. 2008)[3]. Recent work on open source computer science communities highlights the complex and sophisticated nature of the organizational and governance choices that these groups of scientists can make (Dahlander and O'Mahony forthcoming) and their implications for the nature of the knowledge production (MacCormack et al. 2006, 2008). *However, there remained only limited research that examines the organizational choices of scientists for specific research projects – they choice of collaborations, organization of tasks in the lab, governance of the laboratory. In part this gap arises because of the historic perspective of the scientist as "loan genius." Moreover, the strong sense of autonomy among the scientific community has limited the research on choices that scientists themselves make.*

Opportunities for further research also cut across these levels of analysis with three of key importance:

i) **On what field has the SciSIP research been focused?** In other words, is the analysis focused on a particular scientific discipline or sub-field e.g. biology, high-energy physics, nanotechnology? In my opinion, too large a share of current SciSIP research (including my own) highlights the biologists to the exclusion of other arenas. For example we have little knowledge of the influence of policies on material scientists who, like biologists, rely on complex materials, data, images etc. Our knowledge of chemistry, computer science & engineering remains fragmented.

ii) **On what outcomes has the SciSIP research been focused?** Is the analysis focused on academic publications, patents or marketed products? As noted above, these outcomes are now well documented in the SciSIP literature. More emphasis however should be placed on linking up different measures i.e. publications and patents and finding metrics that capture commercializable or commercialized products (see Williams 2010) or measures that capture the broader knowledge landscape such as recent analysis of the patenting of the entire human genome (Jensen and Murray 2005). In this regard, data on licensing would be more valuable than patenting data alone and yet such information (for ideas developed using Federal funding) is not available. I would strongly recommend that this be changed to facilitate greater and more systematic analysis using measures closer to the outcomes and impacts of economic interest.

[3] Ben Jones, a leading scholars in the SciSIP field and author of several key papers in this area is currently a senior economist at the Council on Economic Advisors.

iii) **On what part of the outcome distribution are SciSIP analyses focused?** It is important that SciSIP researcher evaluate *which* researchers and *which* institutions were most affected by particular policy interventions rather than simply highlighting the average impact of particular policies. How do policy interventions impact the distribution of knowledge outcomes? While there may be no impact on the mean perhaps interventions influence the distribution of outcomes – with more high and low quality research. How might policy-levers all levels influence different researchers? What is their marginal impact on different groups of scientists: those at elite highly funded schools versus elsewhere, or those with international co-authorship ties[4]. Studies that emphasize these distributional outcomes should be encouraged by SciSIP because it is from the richness and diversity of the scientific community that novel breakthrough outcomes arise. Studies could also fruitfully include analysis of the differential impact of policies on male versus female scientists[5].

SciSIP COMMUNITY

The SciSIP, led by the National Science Foundation with critical input from Program Officer Julia Lane has made tremendous progress in spurring a group of scholars to pioneer studies in the science of science and innovation policy. For some of these scholars, this represented an increase in their commitment to a field in which they already had an interest. For others, SciSIP was a new departure and an opportunity to move into a new and burgeoning field of great policy relevance and with significant intellectual challenges. The time is now ripe to move from funding of individual researchers to extending and emphasizing the SciSIP community. A stronger scholarly community - once established - will provide a number of critical benefits. It will be in a position to design and implement its own **common pool resources** and data sharing infrastructure to ensure that research methods, data and analytic tools are widely and effectively shared among scholars. At the moment there only a limited data-sharing infrastructure: the STARS program represents a key effort to gather new data, however many studies rely on complex historical datasets that incorporate rich and varied data sources but which are not shared across the community. While issues of confidentiality do arise, it is imperative that we follow the lead of the scientific communities we study and build a more effective infrastructure, norms and rules for data exchange and reuse[6].

Community building will also enable a richer interchange across scholars whose disciplinary training and identify lies in different areas. At the present time, my perspective on SciSIP is that there exist various sub-communities largely within disciplinary silos who communicate but with little exchange across these

[4] A distributional approach would enable SciSIP scholars to assess the impact of policies on numerous dimensions: researcher and institution status, nature of the researchers' institution (university, private firm, government lab, etc.); researcher cohort; collaboration type (e.g., within vs. across institution, state, country, and/or field); basic vs. applied research; journal status; article breadth (multiple subjects vs. single subject); journal reputation ("impact factor"); and network characteristics.

[5] Some of my own work has examined the theme of gender in scientific research. In "An Empirical Study of Gender Differences in Patenting among Academic Life Scientists" (Ding, Murray & Stuart 2006) we show that for over 4,000 life science faculty, after accounting for the effects of productivity, networks, field, and employer attributes, the net effect of gender remains: women patent at 40% the rate of comparable men. Other research in this spirit includes Ding et al. (2009).

[6] See Murray and O'Mahony (2007) for a detailed examination of the need for incentives for disclosure, reuse and accumulation in different knowledge communities and how these incentives are provided.

traditional boundaries. For example, those who take an economics oriented approach gather as a community under the rubric of the Innovation Policy Working Group of the Bureau of Economic Research Productivity Program (including the Summer Institute Innovation Policy and the Economy activities). Not surprisingly however, this is not a forum in which sociologists, historians of science and technology or science and technology studies (STS) scholars share their research. In sociology there are few if any systematic gatherings of scholars with science policy interests and SciSIP researchers from STS and organizational behavior share similar concerns. One strong recommendation I have is for the NSF SciSIP program to fund the establishment of a "knowledge hub" that can orchestrate annual or biannual research meetings for interested SciSIP scholars. As I outline below in my comments on structuring SciSIP education, an effective cross disciplinary hub (that could be modeled on the Consortium on Cooperation and Competitiveness (CCC)) with governance from faculty from a number of key universities and rotating responsibility for cross-university research meetings and some (limited) cross-university doctoral training. Such a forum should also enjoy strong input from the NSF but overall would be most effective if it was organized with "bottom-up" support from faculty rather than managed directly by the NSF or other agency.

Building stronger linkages between the SciSIP research community and the community of science policymakers is another key pillar of the broader SciSIP community that remains to be constructed. At the present time, there is limited awareness of the key findings of SciSIP research among policymakers, and SciSIP scholars have only been engaged in a limited way in recent debates over key changes in science policy. For example, in the recent discussions over the role of innovation grand Challenges there was very little scholarly input from the SciSIP community; many prize and challenge designers and implementers were involved but there was little or no discussion of the tradeoffs associated with the use of challenges and the characteristics of the most effective problems that might be solved using challenges (and whose which are less likely to be tractable with this incentive system). Building stronger links to the policy community is a long-term task that starts with the education of a new generation of policy makers to become critical consumers and co-producers of SciSIP research. However in the short run, links could be established with different government research funding agencies through a series of targeted workshops that bring policymakers, agency employees and SciSIP researchers to focus either on the issues, problems and successes of a particular agency or to focus on cross-cutting issues of mutual interest. This is likely to require sustained engagement through a series of regular meetings and dialogues in order to build up trust, mutual respect and an appreciation of the problems and opportunities that our nation's research agencies, researchers and policymakers confront and the tools and insights that might guide them going forward.

SciSIP EDUCATION

Education is a critical element of the SciSIP agenda and should be a central pillar of SciSIP going forward. To date the program has focused largely on research and establishing a community of scholars among established academics. There is a pressing need to determine the best mechanisms through which to build up the educational aspects of SciSIP and to fund this education. The challenge of SciSIP education can be considered along two dimensions –education of producers of SciSIP research and education of consumers/practitioners of SciSIP research.

PRODUCERS

The educational requirements of SciSIP *researchers* are intensive; the approach requires strong disciplinary foundations in the social science. These must then be complemented by three other elements: theory, phenomenon, data/empirics:

- Theory: A perspective of the theoretical foundations that ground our understanding of the behavior of scientists, the scientific community, and scientific progress (these can include a microeconomic approach based on understanding incentives, the role of control rights etc. as well as a sociological focus on norms and practices or a psychological view)
- Data/Empirics: Strong data and empirical skills specific to science and science policy. SciSIP is grounded in a belief that while every scientific research project is different, systematic data gathering, the use of both large-scale analysis (with publication, patent, citation, collaboration data) and granular field-data, and careful empirical design will enable scholars to draw causal inferences regarding the impact of specific policy levers (at the national, regional, agency, university and lab level) on scientific productivity and impact. Therefore education must give researchers the ability to identify, gather and analyze such data
- Phenomenon: A deep appreciation for the nature of scientific work and for the ways in which particular interventions in scientific progress have shaped productivity, impact or direction. This is challenging for scholars without a scientific training but is essential if scholars are to find the most effective research settings for their studies and if they are to make their work relevant to scientists and to science policy practitioners.

The education of the “producers” of SciSIP research is a critical challenge that should be a high priority for the SciSIP community. Specifically, we must strengthen the education of PhD students who will become the leading scholars in the field developing the research agenda, pushing forward and filling research gaps and pioneering new methods for the scientific and rigorous analysis of science and innovation policy. The skills needed to push this agenda forward are two-fold – first a strong disciplinary grounding in the “home’ discipline – economics, sociology, social psychology etc. and second, an in-depth understanding of the theories, data/empirics, and the phenomenon (as outlined above).

Establishing PhD “SciSIP field concentrations” within traditional disciplinary PhDs: In my opinion, it is not fruitful to try and establish a new discipline within universities termed the “science of science and innovation policy”. Instead I believe that it would be extremely valuable establish a “SciSIP field focus” within a variety of PhD programs within traditional disciplines including economics, sociology, public policy etc. At the present time, Public Policy schools are offering PhD degrees with a S&T policy focus. However, the promise of building a “science” of S&T policy is to extend the intellectual community well beyond the usual confines of policy analysis and ground the empirical and theoretical study of scientific productivity and impact in economics and sociology, as well as psychology and other adjacent disciplines. Therefore, as a complement to S&T Policy PhD education in Public Policy Schools it is critical to establish the field of "SciSIP" within the traditional education of PhD social scientists within their traditional departments. [It is worth noting that this is not an effective educational path for those from a scientific background to move into SciSIP. To do so requires a switch into a social science program to learn the foundations of the particular social science discipline followed by a SciSIP field focus].

Let me illustrate the proposal of a "SciSIP field focus" with the case of economics: Building a "SciSIP field focus" within economics would involve establishing a suite of courses and educational materials at a small number of leading departments (who could share materials, exercises, data etc.). This could then be complemented by educational 'bootcamps' which would bring these PhD students together (from across schools) in a common forum to build their skills, build community and hear from leading SciSIP scholars. Such an approach would mirror the development of entrepreneurship as a field of study within economics – an area that was pioneered by the "Entrepreneurship Bootcamp" funded by the Kauffman Foundation and taught at the National Bureau of Economics. The National Bureau of Economic Research has played an important role in coalescing much of the activity around education in the economic foundations of entrepreneurship through the Entrepreneurship Working Group now part of the Productivity Program. This has enabled vibrant cross-school collaboration not only on research but also teaching. At the PhD level this has helped to build up and educate a community of young scholars within economics departments and management schools who now have additional training allowing them to pursue this field within their discipline.

Hub and Spoke Approach: To build a strong and effective SciSIP-oriented PhD educational program will require using Federal education funding to actively seed a "SciSIP" field focus within at least 4 to 5 schools per disciplinary area (with at least two disciplines represented) – the Spokes. This should be supplemented by funding to develop an effective SciSIP 'Hub' for PhD education. The SciSIP Hub would coordinate activities that encourage coordination across these educational efforts, community building activities for the students involved, and the community "Bootcamp". One model to develop and effective SciSIP 'Hub' for PhD education is the Consortium on Cooperation and Competitiveness (CCC) which "links together scholars interested in long-run performance of U.S.-based companies and institutions" but with a recent focus on PhD-level education, training and community building among PhD students from a number of programs (based mainly within leading Business Schools) with the involvement of academic faculty. As they described, "No single U.S. university or graduate school contains a "critical mass" of scholars from diverse disciplinary backgrounds concerned with issues that are primary to CCC. Accordingly, the network structure of the Consortium is a significant source of strength."[7] A similar argument can be made with regards to the SciSIP agenda, suggesting that a similar consortium could be invaluable in advancing the PhD education and the scholarly community.[8]

[7] http://businessinnovation.berkeley.edu/ccc.html

[8] The CCC was funded by an initial endowment of $500,000 in May 1988 by the Walter and Elise Haas Fund. It has also been supported by grants from the Alfred P. Sloan Foundation in New York, the Smith Richardson Foundation, the Pew Foundations, the Ford Foundations, and the Herrick Foundation. From 1990-1995, the Sloan Foundations was the primary funding source for the Consortium. At the current time, the funding for doctoral activities is largely provided by individual schools supporting their students and hosting the event and by the Kauffman Foundation.

CONSUMERS

The consumers of SciSIP research include Science and Technology policy makers as well as scientists and engineers at different stages in their education. Each of these groups could benefit from a deeper understanding of the results of SciSIP research. In particular, it should be a high priority of the SciSIP community to ensure that the SciSIP agenda is well understood within S&T Policy education; S&T Policy graduates are key stakeholders in the SciSIP research community will be leading consumers of our research, and partners in future research design and implementation.

Science & Technology Policy Masters Education: As students with Masters-level education in science and technology policy move out into the policy community, into research-based public policy organizations, and into the funding agencies that are the subject of much SciSIP analysis, they should be educated to be critical consumers of SciSIP research and to be co-producers of that research in partnership with academics. Much SciSIP research is relatively new and involves novel methods that are highly technical in nature and are not always taught to public policy researchers. Therefore, SciSIP has not yet been incorporated as a central pillar into the S&T Policy curriculum. For example, I supervise a number of MIT Technology and Public Policy students each year and find that they do not have an extensive and thorough grounding in the SciSIP approach, methods and results. Nonetheless, the students are quick to learn and start to use this approach in the course of their thesis work. However, it would be more effective to do this in a more programmatic fashion.

NSF therefore has an important opportunity to work with a number of leading S&T policy programs around the country to develop a curriculum for education in the imperative, methods and results of the SciSIP agenda. This will require a distinctive training from that provided to PhD social scientists for a number of reasons. First, these students can be expected to have less grounding in the data-oriented empirical methods that are common in SciSIP research. The focus should be on understanding the empirical approach and critiquing its validity and the robustness of findings rather than on replicating studies. Second, it is critical to share an understanding of the research design of SciSIP projects particularly those that are based on careful analysis of policy changes, policy experiments and other studies with a thoughtful counterfactual basis. This is a methodological approach that has been pioneered within SciSIP (as noted above) and is a critical element in the education of S&T Policy students. A greater understanding of the SciSIP approach will enable higher levels of collaboration between researchers and policy makers in the future. In particular, it has the potential to seed a higher willingness to work collaboratively with scholars to design and analyze policy experiments with the goal of increasing our understanding of the impact of specific policy interventions on scientific progress

Education of Scientists & Engineers: As has long been recognized in our analysis of scientific productivity, faculty and students engaged in leading-edge research in science and engineering play an important and distinctive role in shaping the productivity and direction of their laboratories. Indeed the organization and direction of large and increasingly complex research laboratories with collaborators that cross disciplines, cross universities, and often cross national boundaries is a daunting task. Nonetheless, we provide limited education to our science and engineering colleagues to guide them in this challenging activity. Offerings for scientists and engineers during undergraduate and graduate education are limited. As we develop new knowledge regarding the factors shaping research group productivity and the role of lab leaders in this productivity, it provides another opportunity for the National Science Foundation together with other leading funding agencies to work to provide such education. Effective education for scientists and engineers would involve three elements:

- **Teach science and engineering undergraduates** about the role of science and technology in society and the economy and given them a broader perspective on their technical education by highlighting the role of S&T policy. Focusing on the results of SciSIP oriented research will emphasize the importance of systematic, rigorous and data-driven approaches to policy, institutions and organizations. This will also provide them with tools to guide them in their subsequent careers, since they will run into the problems of the science and technology at every stage of their careers.
- **Provide PhD students** with short courses regarding the ways in which their research can be more productive and have a more rapid impact on society and the economy based on SciSIP findings. Focus on the key interventions in the process of knowledge production (according to the SciSIP framework) – government policies, regulations etc., university policies and practices, organizational choices. Make this relevant through a focus on the career choices they will have to stay within academia, move into business or focus on policy. For those staying at the bench (in academia or industry) examine how to maximize productivity and impact using the results of SciSIP research - organizational choices they have available, the role of incentives in research teams, the most effective collaborative processes they can use, etc. Highlight the key processes involved in shaping commercial impact including entrepreneurship and technology transfer and the SciSIP results on how these are most effectively deployed. Finally highlight the key role of policy in shaping some of their choices. A program of this type has not, to my knowledge been developed systematically for PhD students. This could be done in conjunction with other career-oriented activities provided by the NSF and other funding agencies to recipients of PhD grants and Fellowships.
- **Educate science and engineering faculty** to have a deeper understanding of how they can achieve greater productivity and impact, based on the systematic, evidence-based results of SciSIP research by running short courses at the university level (perhaps for new faculty), examining the organizational and institutional activities that they could undertake to increase the productivity and impact of their laboratory. This could be incorporated into existing efforts on grantsmanship, communications etc. Possible topics could include two dimensions: factors shaping productivity including lab organizational choices, lab size choices, and collaborative models and factors shaping impact including patenting, technology transfer, materials sharing, networking communication etc. Such an approach would provide a platform for sharing the findings of SciSIP research with academic researchers while at the same time having an on the ground impact on the productivity of investments in research. Finding a possible funder of such an initiative would allow for key educational materials to be developed. The participation of key scientific societies in this activity would also expand the set of stakeholders in the SciSIP agenda.

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