Science of Science and Innovation Policy
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September 2007

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1. Title: The Architecture of Collaboration in Transdisciplinary Research Teams

Researchers: Barbara Gray and Raghu Garud (Pennsylvania State University)

Abstract:

Scientific research, so far, has been driven by star scientists working within epistemic communities. Transdisciplinarity (TD) has recently emerged as yet another vehicle for promoting scientific breakthroughs. TD science is based on the premise that scientific breakthroughs emerge through collaborative processes that integrate knowledge across disciplinary boundaries. However, this process is fraught with creative tensions as scientists from different "thought worlds" contribute in an asynchronous fashion to an ongoing initiative to obtain occasional breakthroughs. How such creative tension is managed can critically impact the outcomes of TD research.

Despite the importance of TD science, there is only limited research on the processes that constitute such efforts. This study seeks to develop a new explanatory model of the architecture of TD research in which both its macro-structural and the micro-processual elements that enable translation across these disciplinary boundaries are examined. For instance, recent literature underscores the important roles that brokers play in bridging epistemic communities by facilitating required translation processes. Yet, little is known about how exactly brokers operate in these contexts. For instance, how do they resolve emerging conflicts and what roles do they play in governing TD research? How do brokers impact an accumulative process that requires long periods of sustained contributions from scientists who work in a distributed and parallel fashion, yet whose activities may be punctuated by occasional moments when breakthroughs occur? The first component of this study attempts to answer these questions.

The inquiry frame that is used for this "science of science" project is appreciative of the accumulative yet fundamentally transformative nature of TD research. The research perspective recognizes that the underlying cumulative process is such that any progress that is made over time becomes inscribed into material artifacts, tools and techniques. The second part of the study, therefore, examines these material artifacts that serve as intermediate outcomes marking the progression of a complex and non-linear process. Equally importantly, these outcomes, as they accumulate, serve as platforms of resources shaping the activities of scientists who function in a distributed yet parallel fashion. The study investigates how this platform of material artifacts emerges as part of the research process and how it is transformed in use.

The third part of the study attempts to understand the dynamic interactions between the macro structure and the micro-processes of collaboration through brokerage on the one hand and through translation on the other. Successful transdisciplinary research will, by definition, change the macro structure of collaboration. As this happens, the locus of brokerage will shift from one part of a network to another as critical problems are addressed and as other problems arise. Such a dynamic perspective on the architecture of collaboration has not yet been undertaken.

This research presents a unique opportunity to study TD research collaboration in two settings that have the potential to yield valuable insights. In studying the National Institutes of Health's TTURC initiative, there is an opportunity to see how scientists from 7 different institutions collaborate over time to address emergent issues in a dynamic fashion to generate breakthroughs. The ATLAS/CERN provides the appropriate venue to study how 2,000 scientists and engineers at 151 institutions in 34 countries engage with one another to handle such creative tensions. In this way, the research directly advances one of SciSIP's objectives to understand the creativity process. Drawing on social network analyses and narrative approaches to understanding drivers of key events in collaborative endeavors, the study develops a new explanatory model of the process through which TD science unfolds over time.

2. Title: Estimating the Effect of Exposure to Superstar Scientists: Evidence from Academia and the Biopharmaceutical Sector

Researchers: Joshua Graff Zivin (NBER and Columbia University); Pierre Azoulay (MIT)

Abstract:

By measuring the "training" effects of research grants and synergies across research efforts, this project provides significant and missing elements in the calculus behind the perennial debates about the benefits from public research and appropriate levels of funding. Measures of geographic influence also inform current policy questions about U.S. competitiveness vis-a-vis the magnetic pull that high quality research exerts on the locational choice of firms in an international context. Moreover, since part of this research explores the mechanisms through which knowledge spillovers operate, the project should generate valuable insights about the allocation of talent across organizations and how the technologies and policies that influence the flow of information between agents has important implications for the level and rate of technological innovation within the economy.

The purpose of this project, therefore, is to empirically estimate the importance of spillovers from "superstar scientists" for scientific progress in the biomedical area. The study relies on a unique dataset that the investigators have assembled over the past several years. The dataset has matched publication output, NIH funding and patents for the complete roster of medical school faculty and NIH grantees between the years 1977 and 2003.

The central model of this study estimates the effect that exposure to "superstar" scientists exerts has on the scientific productivity of other researchers within the academic life sciences. Exposure is assumed to be a multidimensional construct, with three distinct channels of influence: (a) co-authorship ("social distance"); (b) co-location ("geographic distance"); and (c) overlap/complementarity of research foci ("scientific distance"). Because scientists do not locate or collaborate at random, particular attention is given to the quasi-experiments that can help tease apart causal relationships from mere correlations. As part of this study, open-source software tools are developed to construct measures of social and scientific distance between individual scientists.

Beyond intellectual contributions to policy debates, this project will have several additional impacts. First, the software developed to measure social and scientific distance between researchers will be useful to a wide range of scholars interested in science and technology policy. The open-source format is designed to encourage future users to modify and improve the software so that research tools in this area continue to advance. This software along with source code and user manuals will be made publicly available at no charge for use by science policy scholars and other interested parties. Second, the software resulting from this study is expected to dramatically reduce the cost of matching individual-level patent, publication and research funding data in the biosciences by making a number of cross-walk files publicly available. Finally, the findings will be disseminated through various media to a wide range of audiences, thereby facilitating an open dialogue with colleagues in the academy, as well as policy makers and firms in the biomedical industry.

3. Title: Measurement and Analysis of Highly Creative Research in the U.S. and Europe

Researchers: Philip Shapira, Juan Rogers and Jan Youtie (Georgia Tech)

Abstract:

Creative capabilities are an important cornerstone of progress in science and technology, and also a precondition for advances in other societal domains. In the context of heightened competitive pressures to foster science-driven business development and the rise of new global locations for research (especially China), research policymakers in the U.S. and other developed economies hope that adjustments to institutional and organizational environments for scientific research will promote not only more efficiency but also boost scientific excellence and creativity. In contrast with these needs, creativity usually is investigated at the micro level through cognitive studies that embed investigators in research laboratories or apply psychological measurement of individual attributes such as intelligence. At the other extreme, it has been measured at the national level using national indicators of publication and citation strength.

This study investigates features of the meso level (team, organizational, institutional) of the research environment, with particular focus on highly creative and unconventional research activities in human genetics and nanotechnology. Building on a recently completed initial pilot study which identified highly creative scientists in these two scientific fields in the U.S. and Europe, this study extends the measurement and analytical approaches to address the question: What features of the environment at the meso level have an effect on the creative achievements of researchers identified by peers and academic awards as highly creative and what patterns, if any, do these effects have in the career paths of these researchers.

With data from a previously conducted survey of peers yielding nominees plus a set of prize winners in the two fields, this project develops a new database of Curriculum Vitae (CV) of the set of highly creative researchers and a comparison group to (1) reveal the influence of meso level contextual factors (team, organization and institutional) on the performance of highly creative research; (2) determine the existence of career patterns as a result of the interaction of the intrinsic ability of individuals and the features of the meso level environment that are associated with highly creative research; and (3) explore the relation of work assessed by peers to be highly creative with other features of a research career such as productivity, excellence and visibility. The study contributes to the methodology of science studies for policy by further developing and extending CV analysis.

The identification of meso level factors in the research environment has implications for research and human resource management, and the design and implementation of funding schemes. Several of these factors--such as award mechanisms, funding programs, organizational set-up of research sites, and facilitation of career-relevant mechanisms--are of interest to university and faculty management, industrial research and development management, funding organizations, and national research policy. The use of comparative fields extends the range of impact. Human genetics is an established biomedical field supported by a relatively stable set of disciplines. In contrast, nanotechnology is a newer emerging and interdisciplinary field. Likewise, this project extends the findings to research and innovation systems beyond the U.S. context. Public datasets containing variables related to creative researcher nominees, creative researcher and comparison group CVs, and awards and prizes will be made available for use by others. The researchers plan to publish results in peer reviewed journals, develop conferences and Web-accessible documents, as well as a policy workshop to further develop the implications of the study with science policy practitioners. Since the study is carried out by an international team and study an international population of scientists, it will strengthen comparative international research linkages and provide opportunities for young researcher training in measurement of creativity and organizational influences.

4. Title: Social Network Analysis of the Collaborative Interaction of Scientists in Academic and Non-academic Settings

Researchers: Christopher McCarty, Nandita Basu and James Jawitz (University of Florida)

Abstract:

This study analyzes the relationship between scientists who work in university settings (academics) and scientists who work in non-university settings (applied scientists in government and industry). Although there is some degree of overlap between these two groups, it is assumed in this study that these are two, more or less, distinct groups with different motivations for creating and applying scientific innovations. The general hypothesis is that structural characteristics of placement within a whole scientific network, attributes of the personal collaboration network comprised of authors with whom one publishes, and attributes of the work environment determine the level of collaboration between academic and non academic scientists. This study applies techniques from cognitive anthropology and social network research to the community of science. It is expected to result in new discoveries about how academic and applied sciences interact, and how these methods may be applied to other areas of the science of science.

The relationship between academic and non-academic scientists in the U.S. is determined utilizing three different methods. First is a web-based survey utilizing the Web of Science, focusing on authors whose current affiliation is a non-academic institution. Second, a sample of academic scientists is selected from the JCR Science Edition of the Web of Science. Personal network compositional and structural variables are calculated from the authors with whom they have co-authored, paying special attention to the representation of co-authors in non-academic settings. These are used as covariates to explain the variability in their H-index, a measure of scientific productivity in academe. The third task involves a case study of the social network relations between an academic community at universities in Florida (hydrology, soil and water science) and the Florida Water Management Districts. This study builds on the most current research in the area of scientometrics that has shown through citation analysis and the study of patent filings the differential involvement of academic and non-academic scientists. It also builds on the researchers' ongoing project, where authors on the Web of Science are surveyed about their attitudes concerning author order and publishing.

This research has potential application to global research funding for science. Implicit within many grant solicitations is the expectation that scientific discovery and innovation lead to application and ultimately societal benefit. Few studies have systematically examined the interaction between the academic science community and applied science, particularly in the U.S. This study includes the cultural motivations within these communities to provide a better understanding of how the structure functions. By understanding the structure of the nexus between academic and applied science, granting agencies may be better able to structure funding to maximize the probability of scientific innovation resulting in application.

5. Title: Examining the Link between Informal Social Networks and Innovation Using Netometrics to Quantify the Value of a Distributed Hetarchical Network

Researchers: Brooks B. Robinson, Martha Crosby, Leigh Jerome, and Laurel King (University of Hawaii)

Abstract:

This study analyzes the interactions between scientists and innovators in an informal virtual hetarchical social network (VHSN) using self-report questionnaires, state-of-the-art social network analysis methods, and customized network monitoring tools. These analyses permit identification of social-psychological characteristics and other variables in the use of informal social networks. If VHSNs facilitate innovation, then they constitute a very low-cost investment that accelerates efficiency and economic growth. More importantly, the study tests the extent to which VHSNs serve as incubators for sharing ideas that are precursors to innovation.

Existing research shows that innovations and related spillovers serve as major sources of economic growth. This study applies an interdisciplinary approach to identifying a new model for an idiosyncratic innovation process by attempting to marry an evolving concept--virtual hetarchical social networks--to a proven concept for facilitating innovation--formal social networks.

Markets involve exchange and, after sufficient forays of low-content information and after sufficient trust forms, market transactions are expected to reflect exchanges of highly-valued information. Nodes are likely to engage in strategic play--seeking to gather as much and as novel information as possible from other nodes based on the perceived trust and reputation assets that they possess, while restricting the flow of their own knowledge. The results of this research serves as foundational knowledge for developing exportable models that can inform the formation of future informal social networks that incubate, enrich and accelerate innovation.

6. Title: Evaluation of Research Groups: An Endogenous Approach

Researcher: Francisco Veloso (Carngie-Mellon University)

Abstract:

Throughout the last decades, tightening budgets and an increasing competition between research projects have stimulated the development of new approaches towards research evaluation. Yet, despite an important evolution, evaluations still have a critical limitation: the boundaries of the unit of analysis are established based on administrative, institutional or geographic contexts of its members rather than endogenous factors (such as co-authorship and collaboration patterns), overlooking the unique and self-organizing characteristics of the research endeavor. This approach stands in contrast with a growing recognition of the importance of the research group as the critical organizing force of the scientific endeavor.

To overcome these limitations, this study develops and tests a research evaluation method that recognizes the self-organizing characteristics of research groups. Instead of ad-hoc definitions of the unit of analysis, the study utilizes patterns of collaboration and the specific body of knowledge that these collaborations entail to identify the frontiers of the focal units, as well as other units that qualify as relevant benchmarks. First, the boundaries of a research group (RG) are identified based on level of cohesiveness of the co-authorship patterns. Second, backward citations (found in the work published by each group) are used to establish its "knowledge footprint" and assess the degree of similarity between research groups. Once the groups are characterized and their peers identified, the performance and productivity of each RG are measured and benchmarked using publications and citations. The method is tested, first, by ranking groups within and across Mexico and Brazil; the new method is utilized with these countries because of an ongoing partnership (through the Principal Foreign Collaborator) with the Mexican Council for Science and Technology (CONACYT) and of the availability of the database of published papers in these countries. Once the method is tested and validated equivalent analyses for a few areas within the U.S. are performed.

Two main results from this research are expected. First, this study develops a research evaluation method that identifies key research groups based on the strength and frequency of the collaboration patterns and contrast their performance against its peers at different levels of knowledge similarity. Second, this work identifies key research groups in the US, Mexico and Brazil; and benchmark their performance with other groups within and across countries.
This study provides an interdisciplinary approach that combines in a creative way bibliometric and network analysis, to create a new research evaluation tool. In addition, the concept of evaluating and benchmarking research groups based on different levels of similarity in the knowledge footprint is an important departure from the current literature. Finally, the method is quite generic and can be extended to other type of focal units, as well as used with granted patents, to identify research and development or innovation teams across academia and industry.

There are broader implications of this study for research administrators and evaluators. The study identifies and benchmarks key research groups within each country. A careful account of the cohesiveness of the patterns of co-authorship combined with the knowledge footprint of the research groups will yield more meaningful and precise evaluations. In addition, this method opens the institutional black box, helping these actors to note the differences between groups; and compare the performance of a group within similar entities.

7. Title: The Causal Impact of Foreign and Domestic Doctoral Students on Knowledge Creation and Innovation in U.S. Universities: Evidence from Enrollment Shocks

Researchers: Ahmed M. Mobarak and Keith Maskus (University of Colorado)

Abstract:

For various reasons, including tighter restrictions on the issuance of U.S. visas to foreign students after September 11, 2001, applications by foreign graduate students to U.S. universities have fallen. This empirical study, based on micro datasets, evaluates one potentially important economic consequence of this policy: the decrease in high-quality foreign graduate students in U.S. academic institutions. This may adversely affect knowledge and innovation produced in science and engineering departments, thereby affecting long-run U.S. leadership in science and engineering and in scientific innovation and knowledge creation. Thus, it is important to develop careful statistical evidence on this possibility.

Using confidential micro-data on all Ph.D. recipients at U.S. universities from 1960-2004, this project creates measures of enrollments in doctoral programs, broken down by national origins of students, field and dates of study, and university and academic department of enrollment. These measures are then combined with data on knowledge and innovation outputs attributable to specific academic departments, including patents, patent citations, research publications and citations, to study whether foreign and domestic graduate students in science and engineering fields contribute to knowledge creation and commercial innovation. The empirical identification strategy exploits variation in economic characteristics and policy in source countries that led to exogenous changes in the potential supply of foreign graduate students for reasons unrelated to U.S. innovation. Of particular interest is the extent to which domestic and international students are substitutes in the production of knowledge and innovation.

A dynamic model of matching between foreign and domestic graduate students with universities and fields of study are simulated with appropriate basic parameters, and then subjected to various shocks (such as changes in wage opportunities for students). These simulations are used to interpret the econometric results and also to evaluate the likely impacts of alternative policies regarding student-visa restrictions.

A major concern about declining foreign applications is the potential reduction in the research capacities of American universities and the consequent loss of innovation in the broader economy. This analysis should inform policymakers about whether this concern is warranted and the extent to which reductions in innovation over time are anticipated. It also has the potential to inform federal policy priorities regarding visas and subsidies for research, including grant programs. The project evaluates the innovation impacts of alternative visa restriction policies including a policy that favors higher-quality foreign students versus the current policy that puts some weight on the financial status of applicants. The research can also offer guidance on the potential benefits of accelerated tracks toward permanent residency.

American research universities are increasingly reliant on federal grants and licensing income to support their research programs. This analysis offers strong evidence of the productivity of foreign and domestic graduate students in generating knowledge that supports such revenues. Thus, the results should be informative about the returns generated by investments in universities for grants and graduate training in science and engineering. Further, this research will generate a significant new database linking micro-data on enrollments with measures of knowledge creation and innovation by universities and spillovers into the broader commercial sector. The database should be immediately valuable for (a) future research on knowledge creation in specific fields, (b) management studies of research organization in university settings, and (c) research on grant evaluation.

8. Title: Contributions of Foreign Students to Knowledge Creation and Diffusion (Collaborative Research)

Researchers: Shulamit B. Kahn (Boston University); Donna K. Ginther (University of Kansas)

Abstract:

Since the 1980s, the foreign-born share of scientists and engineers educated in the U.S. has grown substantially. The majority of these students remain to work in the U.S. Many concerns have been raised about possible negative effects of this increase on the U.S. and on the sending countries. However, there are also many potential benefits associated with educating foreigners for Ph.D.s in science and engineering. This project has two significant contributions to the literature. First, by analyzing patent citation patterns between foreign-born U.S. Ph.D. recipients' home country and the U.S., this study investigates whether foreign science and engineering students receiving U.S. doctorates help diffuse knowledge from the U.S. to other countries or whether knowledge flows from other countries to the U.S. The study also empirically tests whether knowledge diffusion depends on the doctoral recipients staying in the U.S. Because the decision to return home is not strictly exogenous, a major identification strategy uses the Foreign Fulbright Fellowship as an instrument for the post-doctoral location of Ph.D. recipients since Fulbright fellows cannot return to the U.S. for two years after graduation.

Second, the study attempts to determine whether foreign students educated in the U.S. contribute disproportionately to increases in the rate of science and engineering knowledge creation, innovation, and entrepreneurship. Finally, because of concern over potential losses to the U.S. if foreign students return home in larger numbers, a third sub-project considers what factors affect the decision of doctorate recipients to leave the U.S. after completing their studies. The two main sources are: (1) a data set based on the early careers of Ph.D. and Masters graduates from three large U.S. universities, and (2) data from the NSF's SESTAT database.

The extent to which scientists can access and make use of scientific and technological knowledge produced by others is an important determinant of economic growth. Physical proximity, social networks, collaboration, and interfirm mobility have all been shown to play important roles in diffusing knowledge. This study contributes to the existing literature on this topic by examining the role of education-induced international mobility in explaining global knowledge diffusion.

Some researchers argue that foreign-born scientists are a source of strength for U.S. knowledge creation and innovation. Evidence of this has focused on the most successful scientists or on very specific settings (e.g. a survey of foreign-born entrepreneurs in Silicon Valley). The present study pushes the analysis further by examining whether, in a random sample of scientists, foreign-born scientists are more likely than the native-born to patent and to engage in entrepreneurial enterprises, and whether their patenting is more likely to lead to entrepreneurial activity. The decision of foreign students who receive U.S. science and engineering degrees to leave the U.S. has not been studied at length by economists.

These topics are relevant to funding agencies, particularly the NSF and NIH, in determining the most effective uses of their funding dollars for research and training. By addressing whether and how much the U.S. and foreign countries respectively gain when the world's most talented scientists are educated in the U.S., this study sheds light on whether agencies should direct more funding for graduate and postdoctoral education towards foreigners. Also, it will contribute to the policy debate surrounding high-skill immigrants and their access to student and H1-B visas. Finally, it will help policymakers predict future trends in the share of foreign students in science and engineering doctoral programs and gauge their potential impacts.

9. Title: Models of International Research Collaboration

Researchers: Susan E. Cozzens and Marylin Brown (Georgia Tech)

Abstract:

As world research capacity expands rapidly, the United States science and engineering enterprise finds itself in a new position. Decades of U.S. dominance in science and engineering research helped create U.S. leadership in emerging industries such as information and biotechnology. But U.S. science and engineering research are likely in coming decades to take their place among many strong players on a global scene. Europe, Japan and Korea are already international powers in research and development, and China, India, Brazil, and South Africa are rapidly expanding their capabilities. Under these circumstances, the capacity to monitor the world research front and absorb research knowledge from other countries is more important than ever for the United States. Innovation in the U.S. will thrive best in an open information environment in which our ties to the rest of world research and development are strong. Many factors will contribute to the absorptive capacity of U.S. research. International collaboration is certainly one.

This project explores the benefits of international collaboration for U.S. researchers and their collaborators. Several models for international collaboration exist, including informal versus formal and small versus big science. In order to take a close look at the benefits of collaboration under these models, this study focuses on two fields, bio-fuels and materials science. To compare informal with formal models, an examination is done of each area before and after a formal policy intervention in 2007 that encourages international collaboration (in bio-fuels the U.S.-Brazil ethanol agreement and in materials science the start of the user program at the Spallation Neutron Source). In addition, these examples allow examination of both a small science area and a big science project in the periods before and after a formal collaboration program starts.

The research plan draws on literature- and funding-based data, interviews and a survey. The research contributes to the literature on international research collaboration through its rich mix of methods and its empirical focus on results of the collaborations. It also contributes with comparative design. The interview data compares participants in the interventions with other international collaborators in the same research areas and the secondary and survey data provides comparative information on general patterns of collaboration in those research areas, both before and during the intervention. Through before-after, participant-non-participant, North-South, and U.S.-partner comparisons, sources, benefits, costs, and barriers of a variety of dimensions of international research collaboration are identified. Questions such as whether benefits are mutual, whether the inclusion of junior researchers brings cumulative benefits over time, and whether the two types of programs under investigation have different effects are also explored.

The project will contribute to teaching, training, and learning by involving graduate and undergraduate students at Georgia Tech in every stage of the research, giving them hands-on training in three different methods. The student team will be diverse in terms of both gender and ethnicity, and both senior investigators are women. The project strengthens science and innovation policy networks between Georgia Tech and Colombia by following through on dissertation research of a team member. The results will be disseminated broadly with both scholarly and policy audiences, and will contribute to moving global innovation forward more quickly by providing information on models of effective collaboration.

10. Title: Stimulating Creative Insight - A Cohesive Model of Design Innovation Across Individuals, Groups, and Computer Agents

Researchers: Jonathan Cagan and Kenneth Kotovsky (Carnegie-Mellon University)

Abstract:

Innovation occurs within the minds of designers, within design teams and within computational design engines, each having functional similarities. This project studies the critical elements of creativity and innovation by formally understanding the role of individual cognition in group environments and its relation to computational simulations of the process to enhance the innovation process. An examination of these interactions reveals a great congruence in the structuring of these complex cognitive and social interactions, and the elucidation of the form of that structure and the dynamics of its operation into a model of the innovation process is the major goal of this project. This study could significantly influence how design innovation is structured and pursued in industrial settings. As such, this unique interdisciplinary research in the area of innovation is an appropriate match to the SciSIP mission.

This project rests on the assumption that an individual is working on a difficult design problem as part of a team effort. Often, iterative search within an individual mental representation makes improvements but yields no solution within that representation that meets the design goals. At that point the individual reaches an impasse or block. To overcome the impasse a new representation must emerge, one that occurs through search for a new representation coupled with inputs from the environment. At the individual level impasses can be overcome by appropriate stimuli at the appropriate time in the solution process, not too early and not too late.

The model posits that team members collaborate to develop a common representation within which a solution is found. The individual's representations influence other group members' representations and contribute to the overall group representation, and group discussions stimulate changes to both the individual and effective group representation, the group inputs acting as the external environmental stimuli to overcome the impasses mentioned above. Individuals then work with and develop their own representation, and at times collaborate with the group to both challenge and expand the group's representation as they search for solutions to the design task.

Software agents can emulate and support the group process, providing deeper understanding of the process and means to create a new type of design assist tools at the innovation level. The software agents use a given representation but, based on collaborative strategies, that representation can evolve as the agents work together as a team.

This study develops: (1) an understanding of the common structural and dynamic operations that occur throughout the design process; (2) a better understanding of how humans solve difficult design problems; (3) a deeper understanding of how people represent design problems and a resultant method for changing representations of a problem so as to find creative solutions; (4) a computer tools that build on these findings to improve search of a design problem; (5) an understanding of the relationship between individual problem solving and group problem solving; (6) a methodology and algorithm for group design processes; (7) new methods to assist humans in the creative process both as individuals and, through more efficaciously linking individuals within teams, as teams, so as to empower that process; and (8) the emergence of an empirically anchored theoretical model of individual and group cognition in design. Formalizing a deeper understanding of how individuals participate and adapt in creative team problem solving, and how the team develops into a more efficient set of individuals is one broader outcome of this work. The cognitive understanding will inform the fundamental understanding of the cognition of creative problem solving and in particular design. Computational tools based on design agents can effectively generate innovative solutions.

11. Title: Design Tools to Cognitive Processes to Innovation

Researchers: Christian D. Schunn and Michael Lovell (University of Pittsburgh)

Abstract:

The U.S. is facing serious challenges in the fields of science and technology and our future engineers must use innovation to generate new products, create employment opportunities, and strengthen the national economy. Furthermore, the existing connections between cognitive science and engineering are nationally quite small. This study provides a much needed diverse set of investigators to bridge knowledge across these areas.

Engineering design is a rich interplay of physical and mental. Successful design engineers move from ideas to completed designs using artifacts and tools. Over the past several decades, the number of tools and artifacts available to engineers has become nearly limitless. These tools include drawing programs, quantitative modeling software, sketch paper, computer aided design programs, and prototyping facilities. Despite their importance for supporting creativity and innovative ideas, little is presently known about how tools differentially support innovative design. A lack of knowledge how these tools impact innovative design limits improvements to tools and practical knowledge of how and when to use those tools in design.

The goal of the current study is to begin to build a fundamental understanding of the cognitive processes underlying the role of tools and artifacts in the innovative design process, by combining strengths in cognitive science research and innovative design education (Swanson Center for Product Innovation) at the University of Pittsburgh. A large-scale experiment that examines the ways in which artifacts and tools contribute to innovative design is conducted. This experiment is used to collect a massive database of design activities, consisting of approximately 3,000 hours of video from approximately 60 undergraduate and graduate-level engineering design teams using cyber-infrastructure for video collection leveraged through this grant. The video is then strategically sampled to unpack the causal path from design/tools artifacts in the environment, to core cognitive processes underlying design, to dimensions of design creativity, to the ultimate success of the designed object. In addition, new engineering design innovativeness metrics are developed, validated, and refined. The merit of this study lies within the fact that such a comprehensive study on the learning of design tools and artifacts will substantially expand the understanding of the fundamental processes involved in this important, but often overlooked field.

At the completion of this study, it is expected that the knowledge gained will allow the investigators to lead the development of a new suite of design tools and strategies for supporting practicing engineers and educating engineering students. These tools and strategies could have far reaching implications as they could initiate substantial changes in design practice and engineering design education. This study also involves an enormous data collection effort. The resulting video database will provide volumes of data on the role of tools and artifacts in innovative design, only a small portion of which is to be analyzed during the grant period. This video database will foster considerable follow-up analyses for years to come. The resulting video database will be disseminated throughout the academic community.

12. Title: Developing the Science of Science and Innovation Policy: Profiles of Innovativeness and Gaps in the Idea Innovation Network

Researchers: Jerald Hage and Jonathon Mote (University of Maryland)

Abstract:

Knowledge creation and transfer are conceptualized as part of a system of knowledge production that connects basic science with societal outcomes (such as economic growth and national security). Hypotheses about knowledge creation are derived from the management of innovation and the organizational sociological literatures. Hypotheses about knowledge transfer, or more specifically gaps in transfer, are derived from the idea innovation network theory. Rather than viewing the knowledge production system as a single system, this study recognizes two primary sources of diversity: four different types of research projects defined by the strategic choices of the relative emphasis on normal science vs. high risk breakthroughs and small vs. large size projects; and the differences across scientific disciplines.

Four critical methodological problems are addressed in this study. The first is to test for differences in the profiles of the four kinds of research projects as defined by a research environment survey that the researchers have developed and administered in several research organizations. The second is to attempt to measure innovativeness in real time with measures of technical progress and then correlate these with later measures of papers and patents. The third is to study the amount of technical exchange that is associated with various indicators (collaborations, joint papers) typically used in network analysis. The fourth is to measure the impact of cognitive distance on cross-functional teams and diverse functional collaborations.

The potential impacts of this study are both intellectual and policy oriented. The findings would contribute to the management of innovation and organizational sociology literatures because concepts are defined in new ways and the research setting (science) is different. The most important intellectual contribution is the synthesis of these literatures with those on the idea innovation network and inter-organizational theory, which results in the recognition that the fundamental problem is the identification of gaps in the knowledge production system.

The broader implication of this study rests not only on its contribution to a science of science and innovation policy platform but its contribution to a number of problems in the social sciences. The policy impacts are both immediate and long-term. The immediate ones are that descriptive reports are provided each participating department at selected national labs and center on 42 attributes of the research environment survey a few months after the data collection; a comparative report on the findings including differences by the type of the research project is provided at the end of the three year project. The long term impact is on the construction of econometric models of innovation in which the research organization is the micro unit. In particular, providing a way of measuring gaps in the knowledge production system is a critical policy issue as well as a new theoretical problem.

Another contribution is the continued validation of the research environment survey for measuring innovativeness in different kinds of projects. A survey will be administered to all members of two departments and two centers at Brookhaven, Pacific Northwest, and Sandia National Laboratories, as well as one department and one center at Ames, the National Renewable Energy Laboratory, and the National Oceanographic and Atmospheric Agency. Further, a survey will be administered to 72 projects selected by middle managers at each of the laboratories. Projects will be selected that represent all four kinds of research projects defined by the survey, and project leaders will provide measures of technical progress to assess the surveys ability to assess innovation. Middle and top managers will report on mechanisms for encouraging integration across cognitive distances, strategies for the reduction in gaps in the idea innovation network and the characteristics of the five disciplines.

13. Title: Modeling the Dynamics of Technological Evolution

Researchers: Doyne J. Farmer, William Brian Arthur, and Jessika Trancik (Santa Fe Institute); Douglas H. Erwin (US National Museum of Natural History); Walter W. Powell (Stanford University); as well as several senior collaborators

Abstract:

The aim of this study is to develop an empirically based, quantitative model of the dynamics of technological evolution. The goal of this model is to explain how technologies are related in a dynamical network and why certain technologies improve faster than others. The project focuses on examining both incremental improvements and radical new discoveries that are based on fundamental scientific advances. This problem is approached from diverse points of view, with an interdisciplinary team including economists, engineers, physicists, biologists, and a sociologist.

While model construction is the main focus of this project, several tools are developed in the process, taking advantage of the researchers' experience in complex systems analysis. These tools include developing best-practice guidelines for making technological performance forecasts. Work on portfolio theory, and specifically in designing portfolios under increasing returns in the energy sector, should also provide a useful decision-making tool for public and private actors investing in low carbon energy technologies.

This study consists of an empirical component, theory and model construction, and a simulation component. In the empirical component of this project several large data sets are constructed and analyzed. The project begins with testing of Wright's law, which states that the cost of manufacturing a given technology decreases as a power law when plotted against the cumulative number of units produced. Alternative performance curves are explored, including replacing cost with other measures of performance, and replacing cumulative number of units with other measures of prevalence. The study focuses on both radical new discoveries and incremental improvements, by relating patent and scientific literature data to performance curves. The empirical work includes broad studies of as many technologies as possible, as well as a few in-depth studies of technologies where there is a more detailed view of all the factors that influence technological improvement. These detailed case studies largely deal with energy technologies, an area with societal relevance.

The theoretical component improves on existing models of technological evolution. The operating assumption is that technologies must be studied as part of an ecology of related entities, including all internal component technologies and all external technologies that influence these components. The focus here is on making more realistic models of these network effects. Connections to innovation in biology and the role of selection are explored.
The simulation component consists of the construction of toy models of technological innovation and a study related open problems in portfolio theory. Wright's Law implies increasing returns, so consequently technologies that are developed early accumulate an advantage over technologies that are developed later. What is the optimal approach to investing when technologies follow Wright's Law? In this context, the portfolio problem defines a highly nonlinear stochastic dynamical system whose properties are far from obvious. The case studies focus on the low-carbon energy sector.

Understanding the likely outcomes of public investments in research and development and of the influence of market transformation programs on technological innovation is critical for effective public policy formulation. The focus here is on energy related policy, and in particular on the problem of public investments to create low-carbon energy technologies. The results of this work will be shared with the international private investment and public policy communities through the London Accord project. The results will also be shared with students from a variety of institutions.

14. Title: Towards a Macroscope for Science Policy Decision Making

Researchers: Katy Borner and Weixia Huang (Indiana University); Kevin Boyack (Sandia National Labs)

Abstract:

Science policy and other decision makers need qualitatively novel tools to help them identify the publications, patents, technology claims, grant proposals, or other developments that are most important or potentially profitable and deserve their full attention. They also need a tool that lets them analyze and mine terabytes of relevant data and presents aggregated results in an easy to understand way, enabling them to increase the quality of their decisions. However, more than just a tool is needed. The design of tools that truly support science policy making requires a detailed characterization and prioritization of the information needs of science policy makers, along with a conceptual framework that links the information needs of the policy maker to the available data, analysis and indicator types. Once these are in place, tool development that truly addresses the needs of today's science policy makers given the constraints of existing datasets as well as theoretical and algorithmic approaches can proceed.

This study addresses three challenges. First, a detailed analysis is conducted of the information needs of a representative set of science policy makers including existing data, approaches and tools. Second, a theoretic conceptualization is developed of tasks relevant to science policymaking that maps the needs of policy makers to theoretically grounded and practically valuable processing pipelines that transform data into actionable information. This conceptualization is then made available online in a wiki-like format for community review and consensus building. Third, a prototypical tool--a macroscope--is designed to visualize structure, patterns, trends, and outliers in science and technology data sets that are too large and complex to be comprehensible to the researchers through direct observation--just like microscopes and telescopes make it possible to see things that are too small or too far away. The prototypical macroscope supports a well defined set of information needs, e.g., identification of emerging research frontiers or correlation of funding with publications and patents in an area of research and exploration of results using graphs and geospatial and science maps. Macroscope tool development will benefit from the NSF funded Scholarly Database (SDB)) that provides access to more than 20 million scholarly records, and the Cyberinfrastructure Shell (CIShell), which supports the easy plug and play of datasets and algorithms and the design of stand-alone tools. Usability studies are conducted to evaluate and optimize the macroscope. The macroscope as well as its support of advanced science mapping techniques will be introduced to a broader audience by means of the Places and Spaces: Mapping Science exhibit. Researchers and science policymakers in Japan will participate in this project, generating a bi-directional flow of best theory and practice.

The scientific study and management of science and technology requires a shared terminology and conceptualization of how science works. It requires shared data repositories that can be used to run benchmarks and comparisons of algorithms, to thoroughly validate the combination of algorithms, indicators, and evaluation procedures. The theoretical component of this study, as well as the extension of the SDB and the prototypical design of a macroscope, will create a basic shared understanding and a freely available cyberinfrastructure and tool for the science of science (policy) community.

The same capabilities that could make the macroscope a tool of choice for science policy makers could also make it attractive to other potential users. For instance, students or members of the public will be able to see the large scale structures of science, and find potential areas of interest for further study; researchers will be able to monitor and access research results, relevant funding opportunities, or find potential collaborators within and without their fields of inquiry. Program managers and reviewers will use it to meet their individual needs.

15. Title: Research and Technology Partnerships: Quantifying Strategic Relationships

Researcher: Nicholas S. Vonortas (George Washington University)

Abstract:

This study defines, creates and broadly interprets a large international database of inter-organizational collaborative agreements. The database focuses on research and technology partnerships (RTPs), which constitute an important subset of all innovation-based strategic alliances focusing primarily on the generation, exchange, adaptation, and exploitation of technical knowledge.

Building upon network analysis to understand RTPs as an element of the innovation system, the study: (1) sets forth a taxonomy of the potential scope of inter-organizational activities that fall under the rubric of RTPs (e.g., formal/informal, equity/non-equity, subsidized/non-subsidized, national/international, horizontal/non-horizontal) and formulate policy-related questions that can be addressed if data were available; (2) develops a data collection and database formation technique based on input, output, and outcome indicators; (3) creates a U.S.-based database of national and international RTPs that is structured specifically for addressing policy questions related to the role of alliance networks in information flows among organizations and sectors in the economy and across economies; (4) links the database to other available data sources that can be utilized to address networks in information flows; (5) defines and validate from the database science and engineering indicators related to RTPs useful for policy purposes; and (6) advises the NSF on possible survey questions relevant for the collection of information on RTPs.

Building on network methodology, the study relies on popular press information, as well as on financial disclosures and co-patenting activity, to identify RTPs and to construct the database. The analytical techniques that are used to construct the database, and thus to facilitate interpretation of the data, draw from evaluation methodology as related to networks. Of particular importance is the identification of inputs related to the formation of an RTP, innovation-related outputs from the RTP, and the spillover outcomes associated with those outputs. Based on extant models of the innovation process and the role of policy in that process, a set of science and technology indicators is developed from the data, and the relationship of those indicators to the knowledge base of industries and the complexity of their technologies is investigated statistically to validate the policy relevance of the database.

The final products from the study will be widely disseminated through various channels. The most important and long-lasting one will be a specially designed website for the RTP database, including facilities to access a standard menu of indicators and visual aids as well as the possibility for downloading data with specific queries. Another important channel will be the planned international expert workshop where the database will be rolled out, major analytical questions will be debated, and future steps will be discussed. A third channel of dissemination will be through teaching, doctoral and masters dissertations, presentations to academic and policy forums, and publications in economics, business, and policy journals.

16. Title: Assessing the Impact of Science Policy on the Rate and Direction of Scientific Progress: Frontier Tools and Applications

Researchers: Jeffrey Furman (NBER and Boston University); Fiona Murray (MIT); Scott Stern (Northwestern University)

Abstract:

While the cumulative nature of knowledge is recognized as central to economic growth, the microeconomic and institutional foundations of cumulativeness are less understood. Although "Open Science" is widely recognized to play a central role in the production and diffusion of fundamental knowledge, few formal analyses support this understanding of the impact of policies and practices on the rate and direction of scientific progress.

This study focuses on the development and implementation of novel tools for quantitative analysis of the impact of science policy interventions on the process of cumulative scientific discovery. This analysis extends prior research by exploiting the recent availability of detailed citation data with frontier methods from the program evaluation literature. The approach moves beyond traditional cross-sectional comparisons of citations associated with knowledge in different institutional or policy environments; instead, "natural experiments" are utilized, where the conditions governing access, diffusion or follow-on research funding associated with a given piece of knowledge are changing over time. This approach allows the role of institutions and policy to be disentangled in shaping scientific progress from the intrinsic variation in scientific importance across discoveries. Specifically, the study outlines three types of tools: a differences-in-differences approach to citation analysis, the explicit comparison of changes in citation behavior in different subpopulations, and the development of an approach to recover the "distribution" of the impact of policy interventions. These tools can be fruitfully applied to provide novel policy analysis for a range of science policy interventions, from choices about the level of (and restrictions on) public funding, rules governing access to scientific research materials and data, and policies regarding intellectual property rights for discoveries resulting from the scientific process. In particular, the tools allow for the evaluation of science policy intervention on the rate and direction of scientific progress, and allows for the evaluation of the distributional consequences of policy initiatives. There are three potential applications of the tools in some detail, including (a) the impact of intellectual property rights on the diffusion and use of academic science, (b) the impact of national science policies on the geography and distribution of stem cell research, and (c) the impact of institutions that facilitate the sharing of research resources on the dynamics of knowledge accumulation in life sciences research. In sum, the outputs of the research will include papers that focus on the development of the tools per se, and papers that apply the tools in the context of applications focused on important science policy challenges.

This study will inform: (a) science policy analysis, by developing and implementing tools that can assess the impact of specific policies and institutions on the rate, direction, and composition of scientific activities; (b) the study of the economics of science, by elaborating the microeconomic and institutional foundations of knowledge accumulation, which supports economic growth; and (c) the sociology of science, by highlighting the roles of preexisting relationships, status, and networks in the expansion of the scientific community and explaining interactions between the features of the scientific system and its growth.

More generally, the broader impact of this study is to provide a set of tools for a range of science policy questions that have so far resisted quantitative analysis, and to offer a novel domain for the application and adaptation of frontier methods for program evaluation. In particular, the results of this research will have a specific impact in the economics and sociology of science, as well as in science policy analysis per se. In addition, the study provides a bridge between the explosion of quantitative data about science as a potential new area for the application of tools in the program evaluation literature.

17. Title: Innovation and Technology Implementation: Theory and Policy Implications

Researchers: Diego Comin (NBER and Harvard University); Bart Hobijn (New York University)

Abstract:

Innovation activity determines the growth rate of living standards. Unfortunately, even state of the art models of innovation are too stylized and miss important determinants of innovation activity. Hence, their qualitative and (especially) quantitative implications are inaccurate.

One of the critical determinants of the market value of an innovation is its adoption path. Technologies that are adopted intensively have a higher market value than those that are not. Given the enormous cross-country variation that exists in the intensity of technology adoption, research shows that the effect of adoption on the value of an innovation is important. Of course, the dynamics of technology adoption are also endogenous. Therefore, to explore accurately the role of various science and technology policies on innovation activity there is a need for a theory that integrates the adoption and innovation decisions in a unified framework. The framework developed in this study accomplishes this in a tractable way.

The framework in this study has a couple of significant virtues. First, it is easy to extend the model to accommodate realistic sectoral and cross-country heterogeneity in the costs of innovation and adoption. Second, it is quite simple to calibrate the model parameters using cross-country information on research and development expenditures and technology adoption intensity.

Once the multi-country version of the model is calibrated for each of the Organization for Economic Co-operation and Development (OECD) countries, a Nash equilibrium solution is found for a game played by the 28 social planners (one per OECD country) that choose the innovation and adoption policies that maximize their country's welfare taking as given the other countries' policies. The outcome of this exercise will be a complete and accurate science and innovation policy prescription for each OECD country based on a model that is consistent with the current cross-country distribution of research and development expenses and technology adoption intensities.

There are several research and policy spillovers from this study. First, the methodology presented can be used by other researchers--in economics and other disciplines--that want to model innovation and/or technology adoption and diffusion. Second, the specific predictions from the normative exercise can be used to conduct science and innovation policy in the U.S. and in the rest of OECD countries. Third, the models developed in this study will be incorporated in syllabi designed by the researchers for a second year graduate courses. The insights will be quite intuitive and can be taught at the advanced undergraduate level. Finally, various research assistants are trained, both in dynamic macroeconomic theory and in applied macroeconomics.

18. Title: State Science Policies: Modeling Their Origins, Nature, Fit, and Effects on Local Universities

Researchers: Maryann Feldman and James Hearn (University of Georgia)

Abstract:

Each of the fifty U.S. states has adopted science and innovation policy initiatives aimed at improving economic performance. These policies seek to leverage the research capacities of universities in the state, under the logic that those institutions are essential actors in both increasing the state's prominence as a center for technological and scientific progress and building the state's commercialization infrastructure to facilitate entrepreneurship and firm growth. States have become increasingly active in science policy since the 1980s. Unfortunately, there have been few attempts systematically to study the origins of these policies and the nature of the incentives and mechanisms they provide. Archival records of state programs exist but remain difficult to categorize. Relatedly, little attention has been paid to how individual states' policies relate to the states' socioeconomic, institutional, and academic contexts. Finally, although these policies attempt to leverage universities and move research in specific directions, little is known about how universities are in fact being affected.

To address these knowledge gaps, this study utilizes multidisciplinary theoretical models, extensive longitudinal datasets, and a mix of econometric and case-study methods to examine four research questions regarding state science policy initiatives: (1) Origins: When and why do states adopt science and innovation policies involving universities? (2) Nature: How might state science and innovation policies be systematically described, categorized, and differentiated? (3) Fit: To what extent have state policymakers matched their science and innovation policies to their states' and universities' distinctive characteristics? 4) University effects: What impacts have state science and innovation policy initiatives had on both public and private universities in the state?

This study formulates and investigates multidisciplinary theoretical models to examine how state science and innovation policies come to be formed, how those policies might be systematically described, categorized, and compared, how the policies fit with the states' distinctive socioeconomic and institutional contexts, and how the policies subsequently affect organizational structures, processes, and research capacity of universities in those states. Thus, the project is designed to build understanding of not only why states and institutions have acted the way they have but also, perhaps even more fundamentally, the range of potential state actions possible, the reasoning behind them, and their likely effects.

At the same time, this study is designed to inform policy development and for the development of understanding and infrastructure for future projects. Questions about the origins, nature, fit, and university effects of state science and innovation policies are certainly not trivial. State policy initiatives hold prospects for stimulating innovation and broader economic development, but they pose trade-offs against other state priorities. State efforts to develop markets for knowledge may significantly alter university incentive systems and behaviors in ways that may threaten prospects for innovation and continued U.S. competitiveness. Until researchers begin to conduct informed across-state and across-institution analyses, state officials will continue to invest in science and innovation policies without sufficient information on the range of potential alternative choices and their implications. Ultimately, of course, states are interested in the implications of their policies on economic growth. Effectively addressing those ultimate outcomes depend upon first understanding the intermediate issues addressed in the four research questions outlined here. This study is designed to provide foundational models for subsequent, comprehensive investigation of the longer-term economic influences of states' investments in science and innovation policies.

19. Title: Public Value Mapping: Developing a Non-Economic Model of the Social Value of Science and Innovation Policy

Researchers: Daniel R. Sarewitz (Arizona State University); Barry Bozeman (University of Georgia)

Abstract:

Science and innovation policies (SIPs) aim at mobilizing knowledge in support of a wide range of societal aspirations and values. However, analytical tools and models for the assessment of SIPs focus predominantly on economic values. Analytical tools for assessing social impacts of science tend to be anchored in microeconomics (e.g. benefit-cost analysis). The assumptions upon which economics of innovation models and attendant tools are based inevitably affect SIP assessments and choices. For example, the tendency to focus on "science and technology as the engine of economic growth" has contributed in part to the limited attention to equity in the distribution of the impacts of research activities. Values not easily expressed in economic terms receive less attention simply owing to the absence of compelling and concrete ways of thinking about them.

Nearly all observers, including economists, recognize that some social values are not well accounted for by economic models and measures. The influence of economic models in SIP is in part explained by limited progress in developing ways to conceptualize those science- and innovation-related values not easily expressed in monetary terms. The purpose of this study is to further develop a public-values-based model for SIP. At the core of this work are two fundamental questions: What are the public values that justify particular SIPs, and what is the capacity of a given SIP to yield outcomes that support and advance those values?

The research operationalizes these questions and applies them to the development of a SIP decision model using a method that the researchers term Public Value Mapping (PVM). Core assumptions of PVM are: (1) that it is possible to identify public values, including ones not well captured by economic constructs; (2) just as one can assess market failure, "public value failure" occurs when neither the market nor the public sector provides goods and services required to achieve designated public values; and (3) innovation can be characterized not only in terms of contributions to economic growth and productivity but also in terms of public values achieved.

This work entails theory development as well as case studies to advance and test the PVM model. Four case studies (as well as three additional studies funded from other sources) are then inter-linked by a common analytical framework, bringing multiple perspectives to the analysis. Case studies are designed specifically to draw from current PVM theory while also testing and improving the theory. Each case begins with an explicit statement of the public values analyzed, and proceeds to "map" progress toward public values by modeling the distinctive innovation process in which each case is embedded. Integration of case studies adds empirical robustness to the PVM model.

A new model of innovation based on widely shared, non-economic values--public values--would represent a major intellectual advance in the study and analysis of science and innovation policies. This study: (1) advances understanding of the links between SIPs and public values; (2) further develops Public Value Mapping in terms of a "churn model" of innovation, emphasizing the social impacts of innovations and the capacity of innovation systems to create new beneficial impacts; and (3) develops the PVM model as a new theoretically and empirically grounded foundation for assessing and designing SIPs.

The new model of innovation will provide SIP analysts a theoretical and methodological foundation for assessing and informing science and innovation investment and institutional design decisions, using public values as the measure of success. The model is also meant to be a crucial first step toward developing public-values-oriented SIP decision tools that could be widely deployed in SIP decision making processes.