SCIENCE OF SCIENCE & INNOVATION POLICY
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JULY 2008

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1.Title: The Division of Innovative Labor: Features, Determinants and Impacts on Innovative Performance

Researchers: Ashish Arora (Carengie Mellon), Wes Cohen (Duke) and John Walsh (Georgia Tech)

Abstract: Innovation is becoming more open, often involving multiple organizations in a division of innovative labor (DoIL). The division of innovative labor in the economy is conceived of as the distribution across firms and other organizations of the following steps in the innovation process: 1) research/idea generation; 2) development; and 3) commercialization. Despite its importance, there is little broad-based, systematic evidence on the extent or nature of the DoIL, on its impact on firm performance or on the rate of technical advance.

This project collects the first systematic data on the DoIL in the United States by surveying over 20,000 firms in manufacturing and selected service industries. The collected data quantify a number of key features of the DoIL: the extent to which startups, as compared to established firms, are generators of new ideas; the importance of universities as sources of industrial innovation; and the extent to which firms' use of external knowledge inputs increases their innovative performance. They also provide the basis for developing and empirically testing formal models of the DoIL and its effects on innovative performance.

Broader Impacts: This project is the first national effort to collect data on innovative activity generally, going beyond R&D and patenting. It is an important addition to the data infrastructure required for a science of science and innovation policy. The research also informs both public policy and firm strategy by generating new data on innovative activity, creating new metrics, and developing new models of the innovation process,. The research should contribute to deliberations on intellectual property policy and policies on standards and cooperative research and development agreements that potentially affect the growth of technology markets and the DoIL.

2.Title: The Rise of International Coinvention: A New Phase in the Globalization of R&D?

Researcher: Lee Branstetter, Carnegie Mellon University

Abstract: The geography of innovation is shifting, and emerging economies in areas like China, India, and Eastern Europe are poised to play an increasingly important role in the global innovation system. While this shift is currently at an early stage, its reality is increasingly accepted by economists, corporate R&D managers, and policymakers. The shift has raised profound scientific questions as well as significant policy concerns. Standard theories view the emergence of innovative capacity in frontier technologies as one of the final stages in a development process that usually stretches over decades. China and, especially, India are still in the early stages of this conventional development process, yet they are already hosting R&D centers sponsored by the world's technologically elite firms. Is the conventional understanding now obsolete?

Tracking patents granted by the patent agencies of the United States and Europe to inventors based in emerging economies provides a useful way of measuring the shift in R&D to these regions. Investigation of these patents highlights the importance of a phenomenon that may partially explain this shift. A large and growing fraction of these patents result from international coinvention – that is, teams of researchers based in different countries combining their skills and knowledge to generate patented inventions. Analysis of coinvented patents suggests the R&D process can increasingly be disaggregated into multiple stages, which are then each located where they can be undertaken at lowest cost. This project combines quantitative and qualitative techniques to assess the degree to which an international division of R&D labor is emerging, from which both developing and developed nations can benefit. The project also measures the degree to which international coinvention has driven growth in the quantity and quality of research activity in emerging regions.

Broader Impacts The shift in the geography of innovation will have significant implications for the United States, an economy whose prosperity is largely built on its technological dynamism. Is American technological leadership threatened by these developments? What are the appropriate policy responses? Exploration of the role of international coinvention sheds useful light on these issues. Because growth in invention in emerging economies has been heavily reliant on research inputs from Western firms, it poses less of a direct threat to the economic welfare of advanced industrial countries than has been supposed. In fact, by improving the efficiency of the R&D process and allowing firms to explore more technological opportunities with a given level of expenditure, international coinvention can generate net positive effects on U.S. economic growth and end up reinforcing American technological leadership rather than undermining it. The insights associated with the investigation of the coinvention phenomenon and its impacts also help research managers consider and leverage this approach towards improving their R&D productivity, and economic impact.

3.Title: Modeling Innovation Chains Using Case-Based Econometrics

Researcher: Kenneth Flamm, University of Texas, Austin

Abstract: Much of the literature on technological innovation focuses on analyzing measures of the scientific, technical, or commercial productivity of specific types of innovation-related activities in isolation. It does not consider the overall productivity of the linked sequences of these activities that constitute an ***innovation chain***, from scientific discovery through commercialization. There is a gap in understanding of how different types of individual innovative activities come to be linked sequentially in a chain of events that ultimately may produce new commercial products or processes. Similarly, little is known about the organizational and institutional determinants of the overall productivity of linked sequences of such innovative events over time and space.

This project analyzes the economic, organizational, and institutional determinants of successful transitions between such innovative events, and ultimately, toward commercially successful innovation, at each stage along the innovation chain. Data gleaned from patents, scientific publications, literature and patent citations, licensing agreements, research funding, and collaborative agreements are being used to construct a novel database of spatial and temporal linkages between activities and entities at each stage along an innovation chain, and to develop qualitative and quantitative indicators of knowledge and technology flows within these chains of linked events. The database is being constructed using case studies of nano-electronic innovations in the semiconductor industry, and applications of biotechnology innovations in the pharmaceutical industry. This research focus is inspired by efforts within these two mature high technology industries to experiment with novel strategies to integrate emerging technologies into their innovation pipelines. The variety and breadth of organizational, institutional, and funding strategies used to coordinate innovative activities in these industries provides a rich and varied set of data to be used in developing indicators and understanding of knowledge and technology flows.

Broader Impacts**:** Although this research focuses on the semiconductor and pharmaceutical industries, the analysis should develop more generally applicable stylized facts about determinants of the innovative process. The indicators of knowledge and technology flows being constructed are available for use as data in estimation of econometric models of determinants of the probability of a given R&D project successfully transitioning to commercialization. Analysis of this database using a structural model provides empirical insights into the economic, organizational and structural factors that maximize the probability of success for innovation-related projects. These insights are a significant contribution to the development of a science of science and innovation policy. Further, decision makers in both the public and private sectors should be able to use these results to help choose among different possible organizational, institutional, and funding strategies, and improve the odds of successful innovation resulting from supported projects.

4.Title: Patent Pools and Biomedical Innovation

Researchers: Josh Lerner (NBER) and Jean Tirole, Fondation Jean-Jacques Laffont-TSE

Abstract: The United States over the past two decades has seen an explosion of patent awards across a wide variety of technologies, and a dramatic increase in the volume of patent litigation between rivals. Numerous commentators have suggested that the proliferation of these awards, known as "patent thickets", has had socially detrimental consequences since overlapping intellectual property rights may make it difficult for inventors to commercialize new innovations. Patent pools, which can be defined as formal or informal organizations where for-profit firms share patent rights with each other and third parties, have been proposed as a way in which firms can address these "patent thicket" problems.

Patent pools have been most plentiful and well established for decades in the information technology and communications industries. In the past few years, the biomedical research community has expressed increasing interest in patent pools as a potential solution for increasingly prevalent patent licensing issues in biotechnology-related fields.

This project builds on our existing work on patent pools, trying to understand how the issues faced in the biomedical industries are similar and different to the issues in information technology and communication. The project combines empirical and theoretical research in this endeavor in an academically rigorous manner. The project is deepening our understanding of a crucial "knowledge-sharing organization," an institution, like a standard-setting organizations or open source project, where firms can strategically share knowledge.

Broader Impacts For scientists and others interested in innovation policy, this project advances understanding of how patent thicket problems can be addressed, and the strategies that are most likely to be effective (as well as more problematic approaches). The project leaders are ensuring that the findings of the study are diffused in a variety of outreach efforts, in order to insure that the ideas can have the most impact. This takes several forms. First, the project leaders are involving practitioners as well as life scientists in the academic conference that is being organized on this topic. As in earlier projects, the project leaders are participating in the public policy process, explaining their findings. Finally, the project leaders are disseminating the ideas more broadly through outreach to the popular press.

5.Title: Quantifying The Resilience of the U.S. Innovation Ecosystem

Researcher: Erica Fuchs

Abstract: Government policy today targets firms rather than firm ecosystems. Given the increased fragmentation of firm activities and increased technological interdependency of these firms, this mode of policy-making may be outdated. This research leverages a natural experiment in the converging telecommunications and computing industry to examine the impact on the innovation ecosystem of removing a critical set of innovating firms. Drawing on the results, the researchers seek to define characteristics of innovation ecosystems that could provide resiliency against future shocks.

Despite extensive study, there is little agreement within the academic, industrial, or policy communities on the impact of offshoring on U.S. innovation Previous work by the P.I. has shown that moving manufacturing offshore changes technology development incentives. Her results show that when U.S. firms shift production from the U.S. to developing East Asia, the most advanced technologies that were developed in the U.S. no longer pay. Production characteristics are different abroad, and earlier technologies can be more cost-effective in developing country environment. Building on these results, this project seeks to understand the impact of manufacturing offshore on (1) the innovative activities of the firms that moved manufacturing offshore, and (2) the continued advance of the advanced technologies within the same or other institutions in the U.S. In the first part of the study, the results demonstrate whether firms which relocated manufacturing offshore are following a different technology trajectory from those firms still manufacturing in the U.S. In the second part of the study, the results shed insight into whether the relocation of manufacturing offshore has, in the case of the ecosystem of study, shifted the institutional locus of innovation.

Broader Impact**:** In recent years, there has been rising concern over the ability of the U.S. to remain competitive in the global economy. Understanding how innovation ecosystems react to offshoring is critical to redefining U.S. science and innovation policy and to improving the resiliency of such systems. The results of this study shed insights into the significance of institutional location – small versus large firms, universities, or government labs – on the quantity and direction of innovation. Leveraging these results, the project characterizes critical metrics of innovation ecosystems that may aid in their resiliency against shocks such as a large set of innovating firms moving manufacturing offshore. Metrics may include such units as coupling intensity between manufacturing location and innovative output, institutional fluidity, firm-university patent-publication interdependency, and other metrics that emerge from the result of the study. These metrics can be used immediately by policy-makers to assess ecosystem resiliency, and will enable academics to build on them in future work characterizing industry ecosystems. Finally, the particular technology of study – optoelectronics – is critical to advance in communications, computing, and sensing. Understanding the policy levers to continue technology development in optoelectronics may be essential to U.S. economic and military leadership.

6. Improving Productivity and Innovation Metrics: The Case of Financial Services

Researchers: Carol Corrado, Janet Hao, and Bart Van Ark, The Conference Board and Charles Hulten, University of Maryland

Abstract: This research develops measures of firms' resources devoted to the development of new products and business models in the financial services industry, an activity called "finance R&D." The work helps fill a vast gap in our knowledge of the investment and innovation process for a large and important sector of economic activity in the United States. Traditional R&D spending captures the cost of the "work done" by scientists and engineers because the innovation process in manufacturing is well understood to originate in a laboratory. But where do financial innovations, such as credit default swaps, derivatives, electronic payment systems, ATMs, and the like originate? A recent review of the empirical literature on financial innovation suggests little is known about the process.

The novel aspect of this research is to further develop available measures of intangible investment and capital by exploiting Bureau of Labor Statistics (BLS) employer-based datasets on employment and wages by detailed occupation and industry. The BLS data are used in combination with information obtained from semi-structured interviews with industry executives to build estimates of the "work done" by the employees (or contractors) who conduct the design and development activity in (or for) financial services firms. The interviews leverage the Conference Board's extensive network of business contacts to obtain the required information as well as to generally expand our knowledge of the innovation process in financial services industries. The resulting industry-level series for finance R&D both supplement traditional R&D measures and enhance the PI's macroeconomic estimates of the contribution of intangible capital to U.S. economic growth.

Broader impacts: The need for better metrics of innovation and the knowledge economy was underscored by the Advisory Committee on Innovation established by the Secretary of Commerce. One of its main findings was to better measure business intangible investments, and another was to develop a fuller accounting of the sources of economic growth. The PIs research advances these two goals by working on a large and—from the standpoint of the empirical productivity literature—largely under researched sector of the U.S. economy.

7. Title: Linking Government R&D Investment, Science, Technology, Firms and Employment: Science & Technology Agents of Revolution (STAR) Database

Researchers: Lynne G. Zucker and Michael R. Darby, University of California, Los Angeles

Abstract: This project remedies one of the greatest impediments to rapid progress in the science of science and innovation policy both as a field of study and as a guide to policy. It does this by creating an integrated database which can trace the links from government investment in R&D through the path of knowledge creation, its transmission and codification, and ultimately in many cases to commercial uses yielding a better standard of living and better jobs. Specifically, the project completes, validates, demonstrates the utility of, and makes available to the research community the Science & Technology Agents of Revolution (STAR) Database. This is a transformative platform technology for analyses of the creation, transmission, and use of new scientific and engineering knowledge, the creation of new commercial technologies in pre-existing and/or new firms, and the success of those firms as engines of wealth creation and employment growth. The STAR database integrates and complements key databases on science and innovation by using a system of unique IDs for firms and other organizations and for individual scientists and engineers as they appear as principal investigators, authors, dissertation writers or advisors, inventors, and/or firm officers, directors, and key employees. This is set of identifiers is critical because the most productive of these scientists – the "star innovators" – wear many hats simultaneously.

The STAR database integrates data on government grants, journal articles, dissertations, patents, venture capital, initial public offerings, and other firm data. It links to major public databases via widely used financial market identifiers. In collaboration with the Census Bureau, the STAR and the Census firm and worker databases are linked by a concordance for use by researchers with access to the Census data. The STAR database has three tiers: a public graphics-based site primarily oriented toward policymakers and the media, a public site providing access to researchers for downloads and database queries limited to the public constituent databases or aggregates derived from the licensed commercial databases, and on-site access at the National Bureau of Economic Research providing researchers access to the complete STAR Database.

Broader Impacts: This project provides a shared database that enables work to be done that would otherwise be impossible for researchers not located at one of the few elite institutions where significant parts of the STAR Database are available. Real data bring excitement to classroom assignments on topics that in the abstract can deaden students' interest. Most of the data are available on-line with the commercially licensed part of the data available for building take-away analysis data sets at the NBER and for use within all the Census Bureau's Research Data Centers. These data enable both academic and government researchers to build reliable and tested answers to fundamental administration and Congressional questions about the variety of returns to government investments in research. Zucker and Darby also pursue an active outreach program to get their results to policymakers and the press in a form that they can use.

8.Title: Measuring and Tracking Research Knowledge Integration and Transfer

Researcher: Alan Porter, Georgia Tech Research Corporation - Georgia Institute of Technology

Abstract Enhanced Science of Science and Innovation Policy depends on better metrics. You can't manage what you can't measure. This is particularly true for interdisciplinary research, which currently has few generally agreed-upon measures with acceptable degrees of accuracy. Researchers at the University of Sussex have begun to address this problem by developing a conceptual framework to gauge research diversity. The current project builds upon that conceptual framework to empirically test metrics that gauge the interdisciplinarity of particular bodies of research. One proposed key measure assesses the degree to which particular research papers, or collections of such, *integrate* research knowledge from diverse research domains. A second measure determines the degree of *specialization* of collections of research papers (e.g., those published by a particular research center or those of a research area such as quantum dots). The resulting measures help track and characterize the emergence of new (interdisciplinary) research areas.

The project generates analytical algorithms for indicators of interdisciplinarity. It also seeks to visually depict knowledge interchanges among areas of research activity. Such *science maps* can help identify and characterize focused areas of research--domains--that are sources of knowledge used by other domains. They can also show the extent of intellectual and social networking among both domains and contributing institutions. This project develops effective means to apply and test these new metrics.

The project focuses on nanoscience and nanoengineering (nano), a significant and emergent research domain that extends well beyond traditional disciplinary boundaries. Georgia Tech has assembled a substantial nano dataset that will serve as the main testbed for computing and assessing indicator variations. The research team generates indicator sets and maps of selected nano sub-topics (e.g., molecular motors research). These indicator sets and maps are shared with researchers and R&D managers to gauge their validity and utility. The research team then develops a taxonomy of nano research activity based on identification of coherent research sub-areas.

Broader Impacts These tools better enable scientists, science managers, and Federal science and regulatory agencies to gauge and track cross-domain knowledge transfers. Failure to recognize the full extent and complexity of these patterns could result in major funding and regulatory mistakes**.** The new indicators and accompanying maps help identify leverage points likely to spark advances in science, technology, and innovation. They can also facilitate graduate education by identifying convergent knowledge domains – potentially emerging "interdisciplines." Better understanding of research landscapes can help orient graduate curricula and spotlight promising dissertation topics. More accurate interdisciplinarity measures also contribute to an ongoing National Academies initiative to bolster interdisciplinary research across the US.

9. Title: Early prediction of the impact of research through large-scale analysis and modeling of citation dynamics

Researchers: Marta Sales-Pardo, Luis Amaral and Roger Guimera, Northwestern University

Abstract: The number of scientific journals and the number of papers published in those journals is increasing at a fast pace: currently, there are roughly 9,000 scientific journals, a twenty-fold increase from the 400 scientific journals available in 1955. The size and growth of the research literature places a tremendous burden on decision-making agents, such as funding agencies, university administrators, and reviewers, who have to evaluate the quality of research of individuals and institutions in a fast and efficient manner. In addition, the evaluation of individuals and institutions relies heavily on the assessment of the ultimate impact of published research, typically measured as the number of publications or the number of citations.

Despite the oversimplification of using just a few numbers to quantify the scientific merit of a body of research, the entire science and technology community is relying more and more on citation-based statistics as a tool for evaluating the research performance of individuals and institutions – and the development of tools that facilitate the evaluation task is crucial in order to ensure the highest quality standard for funded research. A major challenge is that stakeholders often want an estimate of the impact of a paper long before citations start to accumulate.

This project aims precisely at facilitating such a task by developing tools to predict, soon after publication, the ultimate impact of research. This project uses longitudinal data available for papers published since 1955, drawing upon the concept that one can infer patterns of citation accumulation from large-scale analysis of historical data.

Broader Impact The outcome of this research is of relevance to decision makers that are called on to evaluate the productivity of researchers and institutions, as well as the impact of their work. The goal of this project is to develop transparent statistically-sound methods in order to enable institutions and funding agencies to make better informed decisions based on an objective assessment of the impact of published research.

10. Title: Universities, Innovation and Economic Growth

Researchers: Sheila Slaughter, University of Georgia and Larry Leslie, University of Arizona

Abstract: Studying the contributions of U.S. universities to the innovation process and National Income is important to understanding how our current economic status has been achieved and to how our international competitiveness may be maintained or increased. This project models a key component of the innovation system, particularly creation and deployment of knowledge and the flows of financial resources. The objectives of this work are to produce estimates of the contributions of various combinations of university resources, especially those of STEM units, to outcomes that represent intermediate steps in the innovation process and that contribute to NI and thus to U.S. competitiveness.

The key insight of the project is that universities produce multiple outputs--for example supplies of highly skilled labor and new knowledge. The importance of this labor and technological development to the national economy has been well established in both classical and evolutionary economic theory. In addition, universities serve as support institutions for firms and industries. Universities contribute to intermediate outcomes that stimulate innovation processes and fuel the national economy.

The primary emphasis is to use data to develop new models explaining the relationships among resource deployment in U. S. universities and intermediate (to National Income growth) university outcomes, particularly in science, technology, engineering and mathematics (STEM). These are outcomes that are important to U.S. economic growth and ultimately to international competitiveness and hence the models can be used to inform science and technology investment decisions.

The project builds a relational meta data base that examines the relationships among resource deployment in U.S. universities and intermediate university outcomes related to innovation and economic growth. The data for the project are derived from a variety of sources at the institutional, departmental, and individual levels. Intermediate and final outcomes include wages paid, the production of graduates, patents, licenses, start-up and spin-off companies, consultancies, joint industry-university grants and contracts, job-training programs for firms' employees, and importantly, research papers. "Inputs" related to these outcomes include various university resources: e.g., the human resources of university faculty, staff, and student workers; the time allocations of these individuals across teaching, research and service; and the allocation of the university's own financial resources.

Broader Impacts: The benefits include advancing understanding of the relationships among resource deployment in U. S. universities and intermediate university outcomes in STEM fields. These are outcomes that are important to U.S. economic growth and ultimately to international competitiveness. Thus, the models can be used to inform science and technology investment decisions.

11. Title: A Social Network Database of Patent Co-authorship to Investigate Collaborative Innovation and its Economic Impact

Research: Lee Fleming, Harvard University

Abstract: Despite evidence that innovation has become increasingly collaborative, our understanding of collaborative creativity and its impact on economic productivity remains incomplete. For example, how should firms structure the collaborations of their inventors, given that networks which enhance the generation of a new idea also appear to hamper the dissemination of that idea? How does knowledge flow within and between regions and how can policy makers influence those flows for maximal social welfare? How does investment in scientific research result in peer-reviewed publication, the diffusion of knowledge, invention, and patenting, and ultimate gains in economic productivity? These questions remain unanswered because social network data are difficult to gather, particularly across time, space, and boundaries. This project permits these questions to be answered by calculating and posting millions of relational data, based on all co-authorship ties between inventors of U.S. patents, from 1963 through the present.

The database complements the National Bureau of Economic Research (NBER) patent database by providing the social networks of patent co-authorships. It creates a standard social network patent database at the individual inventor and aggregate levels including organizational, regional, and technological. It reduces barriers to entry to scholars who lack the requisite programming skills and hardware to create the data on their own and enables real time graphing of patent co-authorship networks. It provides a website by which actual inventors can assess the accuracy of the algorithms used to uniquely identify them in the patent database. Finally, the project provides data on a public website accessible by scholars, business analysts, and students.

BROADER IMPACTS: Just as the original NBER database has unleashed broad and diverse scholarship on innovation (over 500 papers cite it, according to Google Scholar, by early 2008), the social network database project makes possible a similar wave of research, focused on collaborative creativity and the social networks of inventors and their organizations. It enables answering many questions of broad social and economic impact: how managers should structure collaborative relationships and how information flows across organizational, regional, and technological boundaries. It makes possible the tracing the career productivity and mobility of millions of inventors around the world. In conjunction with other databases on research grants and scientific publication, it illuminates the process of knowledge creation and dissemination at many levels of analysis, from the individual, to the organizational, and international.

12. Title: Modeling Productive Climates for Virtual Research Collaborations

Researchers: Sara Kiesler, Carnegie Mellon University and Jonathon Cummings, Duke University

Abstract: An important kind of virtual research organization is the project-based research collaboration involving researchers from different institutions. The project provides a scientific grounding for managing, evaluating, and predicting success in distributed research collaborations. Collaborative success depends on whether investigators have a productive climate -- a social and technical context that supports performance and innovation. In a productive climate, collaborators perceive they have resources to collaborate effectively; they see a link between their achievements and rewards they receive; they experience their group as flexible and welcoming of innovative approaches; and they note minimal conflict between the collaboration and their career and their institution's values. An example of a dimension of the institutional environment that is likely to foster a productive climate is whether the institutions that employ the investigators see exceptional value in interdisciplinary research and have developed practices that support this kind of research. This research defines and measures a productive climate of distributed research collaborations and focuses on a key antecedent of a productive climate -- the institutional environment of the collaboration.

The investigators will study the institutional environments of a sample of projects that were supported by the National Science Foundation. The intellectual contributions of this work lie in the documentation of the importance of a productive climate for distributed research collaboration, and the tracing of the linkages among productive climate and the institutional environments of these collaborations. Better definition of what it means to have a productive climate in research collaborations leads to better metrics for measuring and predicting performance and innovation in collaborations. Identifying the institutional factors that predict the productive climate and outcomes of research collaborations permit the development models to predict which collaborations are likely to be successful.

Broader Impacts: The broader impacts of this project are to inform university, agency, and regulatory practices and policies for science and new forms of interdisciplinary, distributed research collaboration.

13. Title: Dynamics of Creativity and Innovation in Cyber-enabled Scientific Commons

Researcher: Levent Yilmaz, Auburn University

Abstract: Scientific communities in cyber-enabled infrastructures are socio-technical innovation systems that exhibit the characteristics of self-organizing complex adaptive systems. Using empirically grounded and conceptually valid agent simulation models of science, the project explores the minimal structural and behavioral conditions -- the simplest set of assumptions -- for the emergence and sustainment of creativity and innovation in Scientific Commons (SCs). The computer-aided ethnography software, called SC Browser, facilitates ethnographic observation of the social and technical networks in communities such as CreativeCommons, Scholarpedia, CollabRX, and OpenWetWare. SC Browser is inspired by the Actor-Network Theory that focuses on translation networks involving human, symbolic, and physical actors. The software is an advanced analytical tool that aggregates views of interaction among actors and at the same time preserves access to raw research material data sets for qualitative analysis and foundational hypothesis generation. This approach allows computational simulations to be constructed as well as the co-evolution of scientific knowledge, community, and domain practices to be studied in the context of systems model of creativity.

The simulation study (1) considers the discourse of scientific activity, including the contribution of new knowledge in virtual scientific commons, growth of the domain knowledge, and the clustering of research into specialties, (2) views science as an autonomous and self-regulating socio-cognitive system through the introduction of motivation and competitive nature of knowledge production, and (3) explores the impact of alternative community cultures (e.g., exploration-oriented, service-oriented, and utility-oriented), peer evaluation styles (e.g., centralized, decentralized) on the sustainability and innovation potential of SCs. Besides advancing the socio-technical and cultural understanding of cyber-enabled innovation communities, the project produces an integrated and customizable agent simulation framework, called SciSIM, for science policy mechanism design and decision analysis for virtual scientific communities to improve sustainable innovation. Using SciSim, the project demonstrates how social networks and market mechanisms provide a sound formal basis to study dynamics of scientific communities using reliable and valid structural and organizational climate metrics.

Broader Impacts: The project facilitates the training of students to develop computational thinking skills in Science and Technology (S&T) studies. As such, this research advances the state of the art in S&T curriculum via introduction of computational models as pedagogical instruments. Furthermore, the simulation environment and its associated models can be used by science agencies as a computational laboratory for science policy analysis.

14. Title: OPEN PATENT: Modeling Tagging and Visualization Technologies to Enhance Comprehension of Patent Information

Researchers: Beth Simone Noveck (New York Law School) and John Riedl (University of Minnesota)

Abstract: Meritorious patents are a principal currency of an innovation-driven society. They create an incentive for the production of novel inventions. But the system is threatened if a patent application does not reflect a new and non-obvious invention. The arcane language of patent applications conveys insufficient information to enable effective communication among patent professionals and the scientific community. Tagging and visualization, two software-driven techniques that are used to enhance access to digital information, are in common use in commerce, but they have yet to be applied to a vast store of scientific information in the public sphere. Tagging is the process by which a keyword is assigned to an item of information; it describes the information and allows it to be readily searched. Visualization refers to a variety of techniques for graphically representing relationships. These two tools of tagging and visualization open great opportunities for using science to unlock essential information and make it available in a useable form.

The Open Patent project studies the application of tagging and visualization tools in the context of patents. Using social networking tools, the Peer-to-Patent website enables self-selecting technical experts to identify and submit bibliographic information relevant to examining the claims of the patent application. Data from the first year of Peer-to-Patent demonstrates that the public can, and does, contribute information that assists patent examiners in more effectively determining patent eligibility. Using data developed through the Peer-to-Patent project, the Open Patent project takes as its premise that, for the patent system to continue to promote science and innovation, new scientific tools are necessary to enable: patent examiners to understand the claims of an application for which a patent is sought; competitors to know the scope of a granted patent in order to innovate around it; and the scientific and technical public to find and discuss patents related to their research. The Open Patent project studies the effects of user-generated tagging and visualization on the exchange of information in the patent process. The hypothesis to be tested is whether enabling public tagging of patents and applications will: 1) enable scientific research communities to develop knowledge bases of patents relating to their area of research; 2) produce a demonstrable increase in rates of public participation by the scientific community in the USPTO public patent review program; and 3) enable patent examiners to identify more relevant information to assist with the patent examination process.

Broader Impacts: This research has ramifications for improving the quality of issued patents and the exchange of information between a government agency and the scientific public, on an international basis. In addition, this research develops new models, analytic tools and datasets that can also be applied in the science policy decision-making process in many other domains.

15. Title: Integrating Social and Cognitive Elements of Discovery and Innovation

Researcher: Chris Schunn, University of Pittsburgh

Abstract: Innovation and discovery involve individuals working successfully together in teams. It is critical for the Science of Science and Innovation Policy to understand how the cognition of individuals, the direct source of novel ideas and critical decision making, is impacted by social teamwork variables. Prior research has typically studied social teamwork variables in isolation or individual cognition variables in isolation. To know how to intervene to increase engineering and scientific output, the relationships between the two must be known, or else we might improve one at the cost of hurting the other, which likely would have no net improvement in final scientific or engineering productivity. The current project examines a very large quantity of video data collected from a recent highly successful case of science and engineering, the Mars Exploration Rover, which both wildly exceeded engineering requirements for the mission and produced many important scientific discoveries. Yet, not all days of the mission were equally successful. From this video record, the project traces the path from the structure of different subgroups (such as having formal roles and diversity of knowledge in the subgroups) to the occurrence of different social processes (such as task conflict, breadth of participation, communication norms, and shared mental models) to the occurrence of different cognitive processes (such as analogy, information search, and evaluation) and finally to outcomes (such as new methods for rover control and new hypotheses regarding the nature of Mars).

Another critical factor for Science of Science and Innovation Policy is to examine both divergent thinking and convergent thinking. Innovation rarely happens unless new ideas are considered. But progress will not happen unless the best ideas among the proposed set are ultimately selected. To know how to best intervene to improve discovery and innovation, progress must be made on finding out when to intervene, which likely depends upon whether divergent or convergent thinking is currently required. A number of prior inconsistent research results likely resulted from a failure to separately consider divergent and convergent thinking. The current project examines both elements to build a much more complete model of how cognitive and social variables come together to produce new and successful engineering innovations and scientific discoveries.

Broader Impacts. The US is facing serious challenges in the fields of science and technology. Innovation must be harnessed to generate new products, create employment opportunities, and strengthen the national economy. It is vital that the flourishing of science and engineering teams be examined with the same rigor as other important human endeavors. This project also has implications for science and engineering education: as ways of composing, structuring, and instructing teams are examined, suggestions for pedagogy will be formulated based on empirical findings.

16. Title: Inspiration as transmission of creative insight

Researcher: Todd Thrash, College of William and Mary

Abstract: Scientists, inventors, writers, and other creators have attested to the importance of inspiration in the creative process. In contrast, creativity researchers have generally dismissed the concept of inspiration, arguing that ascription of creative insight to the intervention of a supernatural source ("muse") is outmoded myth. However, it is possible to reconcile creators' accounts of inspiration with contemporary science. Inspiration is posited to be an effect of creative insight, not its cause; inspiration is posited to be a motivational state that is aroused in response to a creative insight and that compels the individual to translate the creative insight into a creative product. This perspective exposes an important gap in the research literature. Creativity researchers have made considerable progress in identifying the cognitive, neurological, and contextual origins of creative insight (thus debunking the notion of Muse) but have largely ignored the state of inspiration that promotes the translation of creative insights into creative products. This oversight is striking, because the failure to translate creative ideas into tangible products is likely to be among the most important obstacles to innovation. This project has three primary goals. The first goal is to develop methods for the assessment of inspiration and to provide evidence of their validity. Several methods of assessment are being developed, including self-report questionnaires and objective indicators derived, for instance, from digital video of nonverbal behaviors and from electronic monitoring of the creative process. The second goal is to demonstrate that inspiration is a robust predictor of creativity and other socially valued outcomes, including work productivity and efficiency. Several types of creative activity are examined, including invention, scientific writing, and the writing of poetry. In each case, creativity is assessed objectively (e.g., receipt of patents) or through a peer-review process. The third goal is to establish the functional significance of inspiration by integrating it with contemporary theories of personality and human motivation. For instance, the personality traits that predict the creativity of an initial insight are expected to be fundamentally different from the traits that predict the tendency to become inspired to actualize the insight. In addition, mysterious aspects of the subjective experience of inspiration, such as the feeling that one is functioning as the mouthpiece of a power beyond oneself, are expected to be explained by the involvement of implicit (unconscious) processes.

Broader Impacts: This project has important impacts beyond advancing the motivation, inspiration, and creativity research literatures. Dissemination includes research articles, book chapters, and conference presentations. An additional impact includes the development of tools for the assessment of inspiration, known to be predictive of creativity, productivity, and efficiency, and made available for use in the workplace and in educational settings. Finally, the models equip policy makers and others concerned with societal adaptation to changing physical and sociopolitical environments to understand the processes through which innovative and transformative ideas are translated into concrete products and solutions.

17. Title: Transmission of Tacit Skills in East Asian Graduate Science Programs

Researchers: Marcus Antonius Ynalvez, Texas A&M International University and Noriko Hara, Indiana University

Abstract: This project addresses a crucial area in the globalization of science: the transmission of skills to future scientists. It does this by examining doctoral training practices critical to the transmission of skills acquired through close interaction and hands-on experience, also known as 'tacit skills.' Although an under researched area in scientific training, 'tacit skills' play a crucial role in the creativity and innovation in experimental and mathematical sciences, laser and nuclear technology development. While there is a standard set of accepted scientific principles shared by most scientists, there are also differences in terms of what is learned and how it is taught.

This project focuses on Japan, Singapore and Taiwan. Each of these countries has consistently exhibited high rates of innovation and productivity in recent years. However, while these countries have been successful in science education, each of them approaches the task of training scientists in various methods. The core hypothesis of the study is that student-mentor relationships significantly configure levels of scientific creativity, pioneering discoveries, technical innovation, and research productivity. The project's main goal is to develop an empirically tested and contemporary model of science that will inform science and innovation policy about the role of 'tacit skills' in knowledge production, and to enhance best practices in U.S. graduate science training.

The project analyzes the different methods using analytical, conceptual, and methodological tools from the areas of knowledge sharing, social networks, and the extended translation model of science. While a component of the project will uncover the degree of codified knowledge that is taught by most standard text books and the mastery of this knowledge, the project also seeks to understand advanced knowledge acquisition and transmission through the study of graduate science training by exploring students' relationships with mentors and peers. Contemporary research has shown that the nature of informal educational practices is not only conducive to the acquisition of 'tacit skills' but enhances professional competencies.

Broader Impacts: This project not only advances understanding of how 'tacit skills' are transmitted, but also informs pedagogical programs, and generates 'best practices' in advanced scientific training that recognize the changing nature and morphology of knowledge production brought about by globalization. It enhances scientific manpower and infrastructure by establishing networks of collaborations across disciplinary boundaries among scientific institutions globally. This project involves the active participation of students from underrepresented Hispanic populations located along the U.S.-Mexico border. This participation exposes and socializes these students to actual multicultural research work and to professional scientific careers critical to socioeconomic development of the U.S. southern border.

18. Title: Impacts of Institution-Level Policies on Science and Engineering Education, Employment, Earnings and Innovation: A "Natural" Experiment

Researcher: Catherine J. Weinberger, University of California Santa Barbara

Abstract: It is often difficult to distinguish whether the graduates of a challenging academic program are successful because of their educational experiences, or whether the program simply selected individuals destined for success into the program. It is usually impossible to conduct a true experiment with random assignment of students to educational opportunities. However, large-scale shifts in policy can serve as "natural experiments" that change the way students are matched to educational programs and allow us to identify causal consequences of education. The specific research question addressed by this project is: Do institution-level shifts in the number of science and engineering degrees conferred lead to measurable changes in graduate outcomes—for example: higher earnings, increased participation in the science and engineering workforce, or a larger probability of filing patents—relative to similar earlier graduates? This project examines the outcomes of a concerted effort in 1994 by a group of Historically Black Colleges and Universities (HBCUs) to expand educational opportunities in engineering, computer science and other technical fields, "to prepare their students for expanded career choices." Preliminary evidence suggests that a shift in the relative participation of black college graduates in occupations related to engineering, math, computer science, or physical sciences (EMS) occurred at about the same time. Furthermore, growth in EMS college majors was particularly strong among students most likely to attend HBCUs: those who attended high school in the South. The initial phase of this project is designed to distinguish whether the growth was driven by HBCU policies, or by change at other southern institutions. The second phase involves assembling more than 30 years of data on the number and type of degrees conferred by each U.S. institution of higher education (collected annually by the U.S. Department of Education), analyzing the data to find other examples of large institution-level (or state-level) shifts in the number of science and engineering degrees conferred, and combining this information with data from other sources to discover the resulting educational and economic impacts. The initial phase of this research is designed to reveal the institution-level processes underlying recent expansion of science and engineering participation by a persistently underrepresented minority group. More generally, the research project expands knowledge about the extent to which exposure to science or engineering education at the undergraduate level changes the set of skills college graduates bring to the labor market, and whether that change is substantial enough to affect a whole host of outcome measures including earnings, occupation, and patent activity.

Broader Impacts: The knowledge gained from this research project informs individual-level career-path choices as well as educational and workforce policies. Educational materials appropriate for middle school or high school students are intended teach fundamental mathematics concepts while they convey motivating information-- derived from this research-- about the economic value of pursuing academically challenging educational programs.

19. Title: Funding R&D when Ideas are Scarce

Researcher: Suzanne Scotchmer, University of California, Berkeley

Abstract: The investigators study R&D environments where opportunities to invest are constrained by imagination as well as by resources. This simple and realistic premise has many implications for the design of intellectual property, as well as for other institutions that support R&D. First, since ideas for investments do not arrive simultaneously, there is a tradeoff between preserving options and the cost of delay. Investing early can preempt investments in better ideas that arrive later. An incentive problem arises because a private recipient of an idea may not reap the social benefit of preserving options. This leads to the question of how to organize incentives so that recipients of ideas take account of social options. The investigators characterize a socially optimal threshold for accepting an idea rather than discarding it. The threshold is on the net social value. They prove that the threshold should become less discriminating as time passes without filling the market niche. They then study how reward mechanisms can (or cannot) achieve that outcome. Patents are an imperfect tool because their private value cannot be tailored to R&D cost. Patent value does not scale with social value. In the special case where ideas differ only in the quality of the innovation, but not in R&D cost, patents will over-encourage low-cost ideas with low quality, and under-encourage high-value ideas that also have high cost. Prizes might do better, for example, when ideas differ only in their R&D costs. The prize should increase with delay. Second, because ideas must be compared in order to find the best one, it may be optimal to collect ideas, as venture capitalists do. The investigators illuminate the tension between the social benefits of allowing venture capitalists to collect and screen ideas, and the competitive goals of the patent system. They show that the optimal reward system must be more generous when ideas are aggregated in the hands of a few venture capitalists than when widely dispersed. Third, the scarcity of ideas explains the open-source movement in a new way. In many arenas, there cannot be ideas for further advance unless previous technologies are disclosed. If ideas are scarce, the relevant disclosure cannot be accomplished under contract, because it is not known where the next idea will surface. The disclosure and sharing obligations of the open source community overcome this problem.

Broader Impact: The project improves the design of programs for funding R&D by bringing economic theory into closer contact with the R&D experience of recent decades. For example, the scarcity of ideas should lead to economic profit, as it did in Silicon Valley in the 1990s, rather than to the profit dissipation predicted by patent races. The implications for public funding are substantial. Unlike patents and prizes, public support can be given when the innovator actually needs it, which is before investing. However, giving the money in advance creates a problem for knowing which researchers to fund, especially when the researchers have different idiosyncratic ideas, and different idiosyncratic capabilities. The investigators characterize the optimal blend of pre-screening and experience rating, especially when it is understood that even good ideas may fail.

20. Title: University Research Parks and the Innovative Performance of Park Firms

Researchers: Albert Link, University of North Carolina at Greensboro and Donald S. Siegel, University of California at Riverside

Abstract: This project develops a methodology and statistically implements a data collection and evaluation process for assessing the innovative performance of firms located on U.S. university research parks (URPs). The results from the assessment phase inform the public and private sector about locational investments in science and engineering (S&E) activities occurring on URPs.

URPs have been an important element of our national innovation system for nearly half a century, and in 2007 the "Building a Stronger America Act" (S. 1373) was introduced in Congress under the stated premise that it is in the best interests of the Nation to encourage the formation of new parks and the expansion of existing parks in order to promote the clustering of innovation through high technology activities. Surprisingly, very little research has been undertaken on science/research parks, in general, or URPs, in particular. And, no research has been undertaken on the innovation benefits realized by firms that locate on U.S. parks. This project broadens our understanding of URPs as a component of our national innovation system; develops an assessment tool for assessing the innovation benefits realized by firms as a result of locating on a park; collects relevant data to implement this methodology and offers empirically-based statements on realized innovation benefits from on-park research synergies; and offers prospective statements about the organizational structure of URPs that will be most conducive to enhancing the research synergies among park firms on new or expanded parks.

Broader Impacts: The main intellectual outputs from this research is an assessment of the innovative performance of, and research outputs from, on-park firms relative to comparable firms that are not located on a park. As such, this project's broader impacts include, from a national perspective, the development of park-based science metrics and policy prescriptions to enhance university-driven S&E-based economic development through park formations and park growth. And, from a private-sector perspective, this project informs the locational consideration, and hence future research efficiency, of firms' S&E investments. The project's resulting science metrics inform the consideration of new innovation indicators specifically related to parks. The project's policy prescriptions inform not only Congressional deliberations related to the "Building a Stronger America Act" but also future state and regional S&E investment considerations for building new UPRs and/or expanding existing ones.

21. Title: Comparing Models for Integrating Societal Impacts Concerns into the Peer Review of Grant Proposals

Researcher: Robert Frodeman, University of North Texas

Abstract: Public science and engineering (S&E) funding agencies worldwide rely on the peer review of research proposals to make their funding decisions. Scientific and technical experts are best qualified to judge the scientific and technical merits of proposed research projects. Increasingly, however, society is requiring that S&E funding agencies demonstrate a return on the public investment in S&E research. In response, S&E funding agencies worldwide have incorporated considerations of broader societal impacts into the proposal review process. But asking scientists and engineers to assess the potential societal impacts of proposed research projects takes them beyond the realm of their scientific and technical expertise.

The fundamental question of the research project is: What is the best way to incorporate societal impacts considerations into the grant proposal peer review process? This research focuses on the ways in which different models of peer review incorporate the broader societal impacts of proposed research. The study assesses five different models of peer review—across three US federal agencies: the National Science Foundation (NSF), the National Institutes of Health (NIH), and the National Oceanic and Atmospheric Administration (NOAA); and two non-US contexts: the Natural Science and Engineering Research Council of Canada (NSERC), and the Dutch Technology Foundation (STW). Using both qualitative and quantitative methods (data mining, literature review, surveys, and semi-structured interviews), this research develops usable knowledge by constructing a comparative matrix and analysis of these five models of peer review.

Broader Impact: (1) funding 2 graduate research assistants, thereby laying the foundation for continuing work in the Science of Science and Innovation Policy; (2) integrating this research with teaching at the undergraduate level (in UNT's Ethics in Science course); (3) expanding the network of researchers exploring the Science of Science and Innovation Policy; (4) enhancing the understanding of the process of grant proposal peer review by informing all stakeholders in the peer review process (scientists and engineers, funding agency officials, policy makers, and members of the general public) of the project's results; and finally, (5) improving the peer review of grant proposals, especially in terms of the capacity of various models of peer review to assess the societal impact of proposed S&E research. This project benefits society by improving the connection between the funding decisions rendered through proposal peer review and the societal impact of the funded research.

22. Title: Scholar's Award Proposal for Investigating the Origins and Evolution of the "Basic Research" as a Political Symbol

Researcher: Roger Pielke, University of Colorado

Abstract: Understanding symbols in political discourse is important because symbols shape how policy problems and options are framed. This project focuses on understanding the origins, evolution, and dynamics of the concept of "basic research" in science policy discourse. The exact phrase can be seen as a political symbol representing a concept that has otherwise been characterized as pure research, fundamental research, and transformative research, among other terms. The term "basic research" did not exist prior to the 1920s and currently appears to be falling out of favor.

The topic is of current interest because science policy discussions in Europe and the United States are now characterized by changing language and symbols, and the concept of "basic research" appears to be a causality of this change. In Europe the phrase "fundamental research" has gained some traction whereas in the United States, particularly in the NSF, the phrase "transformational research" has some traction.

Broader Impacts The broader impacts of the research are varied. The origins of the concept of "basic research" are of interest to scholars of science and science policy, but also inform understandings of the evolution of science policies and contemporary debates. An obvious example of the practical implications of such understandings is how R&D budgets are accounted for in the United States. For many years these budgets have been categorized based on a framework where projects are categorized according to the concepts of basic and applied research. If the language of science policy changes to disfavor "basic research" as an important concept, is this change merely cosmetic? Or are there substantive implications for how we organize and think about the domains of science and innovation policy? These questions cut to the core of organization and policy in the National Science Foundation, but also other agencies of government that support R&D, including science agencies in countries across the world. The research dissemination and preparation contribute to education and contemporary policy discussions.

23.Title: A Political-Economic Model of Science and Innovation Policy

Researcher: Mark Zachary Taylor, Georgia Institute of Technology

Abstract: This project addresses an important gap in the science of science and innovation policy scholarship by explaining why well-designed science and innovation policies are sometimes blocked, distorted, or improperly executed. It develops a model of how domestic political variables affect the design, passage, and implementation of science and innovation policy (SIP). The key distinction in this project is that most innovation research takes support for science and technology as given, and then asks which policies can best achieve the nation's science and technology goals. In contrast, this research project acknowledges that technological change creates political and economic winners and losers within society. It then attempts to model the behavior of these winning and losing interest-groups in regards to SIP. History shows that the losers will fight to obstruct, co-opt, or alter otherwise "good" policies that promote science and innovation. Thus, understanding how and why these fights evolve is essential for understanding why some countries are better at science and technological change than others. Put differently, what this research contributes, that previous work has not, is a better understanding of how and why political resistance to technological change arises, and the conditions under which it can affect SIP and SIP outcomes. This project probes the feasibility of applying the modeling approaches that have been successfully used to explain policy development in other important subfields such as free trade, international finance, and economic development, to better explain SIP outcomes. Certainly case studies of individual instances of successful or failed innovation policy have been performed, but a more general political-economic model (such as the one designed in this project) has yet to be presented. This research project therefore opens up a new avenue of SIP research, one with substantial complementarities with existing lines of SIP scholarship. Specifically, it investigates the effects on SIP of: political battles between different interest-groups, different political institutions (legislatures, executives, bureaucracies), and their different policy priorities under changing national economic and security conditions.

Broader impacts: This research helps to explain why otherwise "good" policies and institutions fail to deliver scientific and technological progress. It therefore informs the innovation debates taking place within a variety of disciplines (economics, political science, business, industry studies), each of which tends to omit analysis of the politics behind innovation policies and institutions (or at least lacks a general model of these politics). A successful model also informs the policy process. It identifies the conditions under which certain policy designs might be more or less likely to be passed and properly implemented by government. This can aid strategies for achieving more widespread political support for SIPs and their implementation, and thereby help policymakers deliver more effective SIPs. The products of this research are being disseminated online, at academic and policy research conferences, in graduate and undergraduate level courses, and in peer-reviewed journal articles. The project contributes research training by involving a graduate student research assistant. Therefore this project impacts research, policymaking, and student communities.