Science of Science & Innovation Policy

Julia Lane

Overview

1. A summary on what approach is being taken to evaluate programs, particularly the choice of outcome measures and counterfactuals.
2. A brief discussion on the types of data that are being used in evaluation, and a critical evaluation of the advantages and disadvantages.
3. A discussion of what steps are being taken to advance the science of evaluation in the US

Science of Science Policy Interagency Group

- Formed under Committee of Science
- 17 agencies participating
- Cochairs Bill Valdez (DOE), Julia Lane (NSF)
- ITG engaged in a number of activities
  - Questionnaire
  - Literature review
  - Roadmap

What we have learned

Since the Science of Science Policy (SoSP) research program was launched in FY01, we have learned the following:

- Qualitative methods (peer review, expert judgment, logic models, strategic planning, case studies, committee of visitors, etc.) remain the gold standard for policy makers who use decision support tools when making R&D investments and policy decisions.
- The best emerging quantitative decision support tools (risk analysis, dynamic modeling, network analysis, datamining, etc.) rely heavily upon expert judgment and advice from the scientific community to be successful.
- Considerable progress has been made on process metrics for science program management, but outcome/impact measures are still in their infancy.
- The traditional tools of R&D evaluation (bibliometrics, innovation indices, patent analysis, econometric modeling, etc.) are seriously flawed and promote seriously flawed analyses.

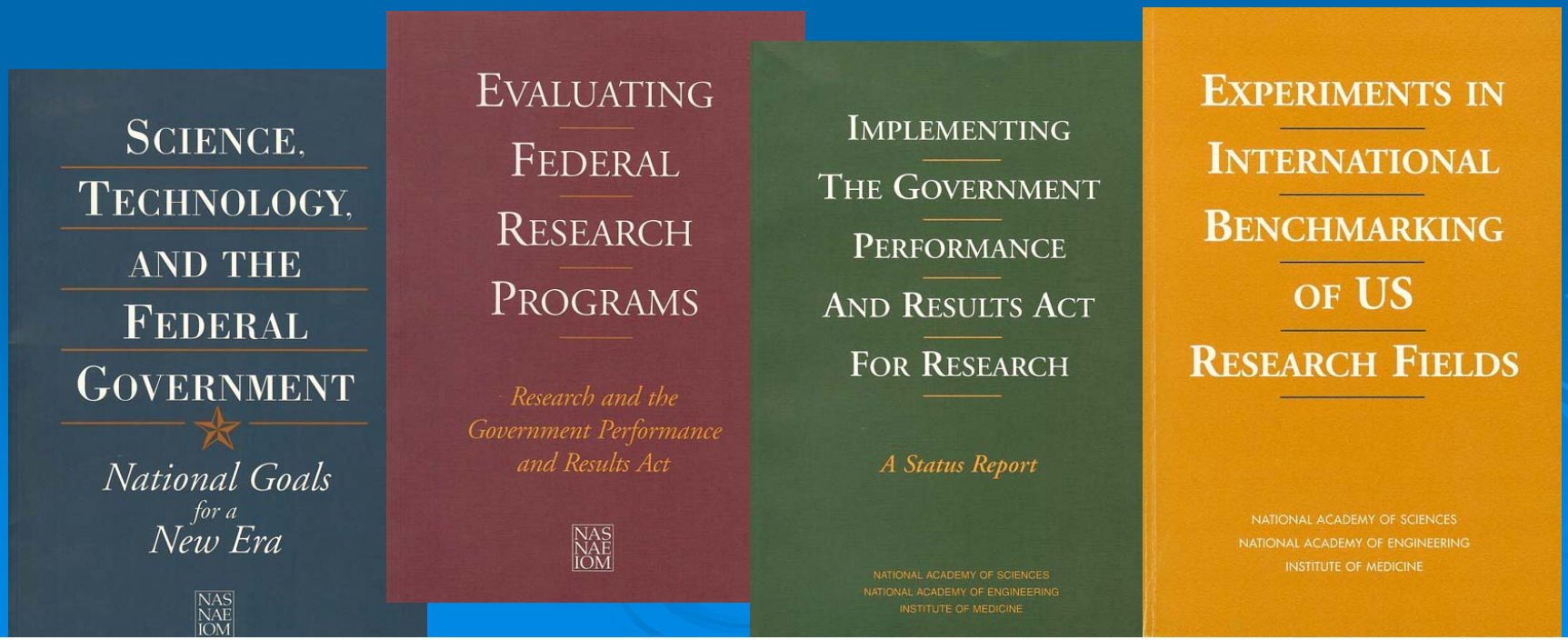
Source: Bill Valdez

What we have learned

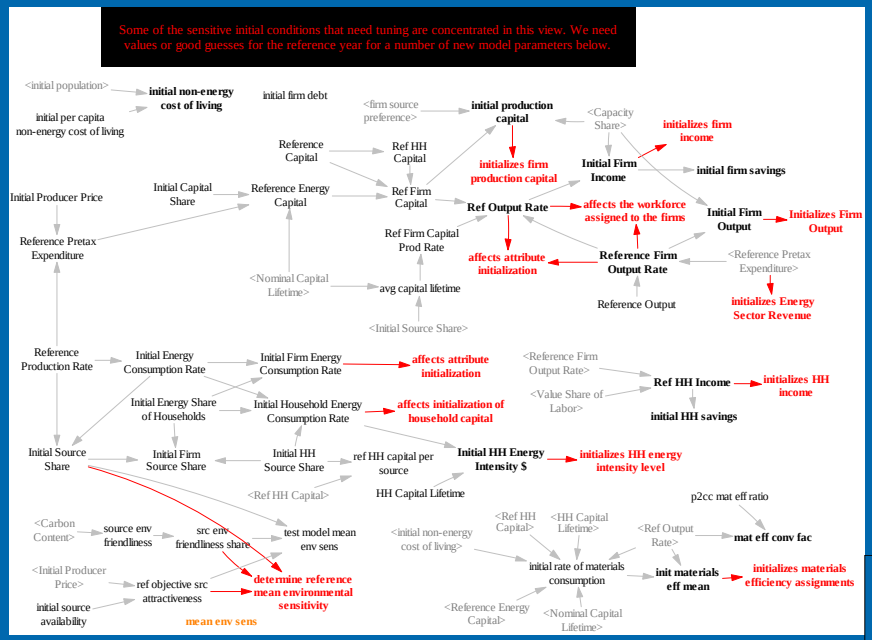
- There is very little capacity within the Federal government to conduct science policy analysis and evaluation. This is caused by both resource constraints (total Federal investment in this area is less than $20 million/year) and an absence of a defined set of effective practices.
- Perhaps the greatest barrier to effective analysis is the absence of reliable data.
- The scientific community is skeptical about the use of new decision support tools, but is open to a discussion, particularly one that centers on decision support tools that are scientifically rigorous and transparent.
- There is great confusion about the problem set being tackled, primarily because there is great confusion about the definition and use of key terms (i.e., innovation, discovery, basic research, mission-driven research, etc.).
- There is no agreed upon model of national innovation. This means that there is no agreement about what makes one system more innovative than another.
- **Because of the above, reports like the "Gathering Storm" the provide seriously flawed analyses and misguided advice to science policy decision makers.**

1. Qualitative Methods – Gold Standard

Qualitative methods (peer review, expert judgment, logic models, strategic planning, case studies, committee of visitors, etc.) remain the gold standard for policy makers who use decision support tools when making R&D investments and policy decisions.



2. Best Tools Need Expert Scientists



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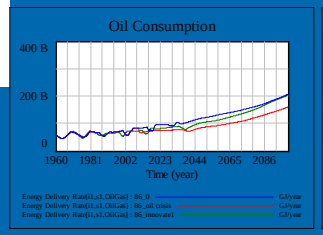

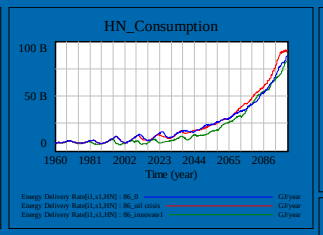

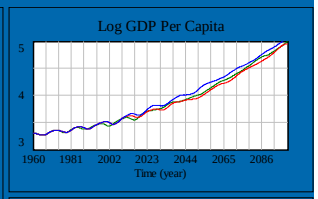

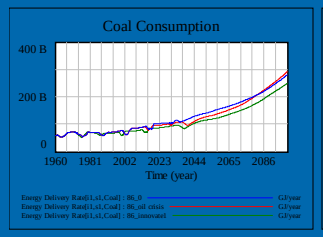

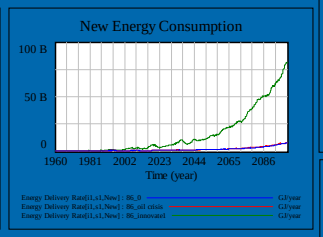

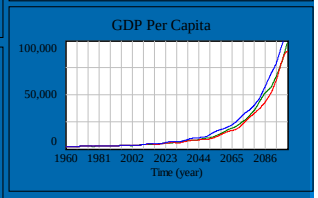

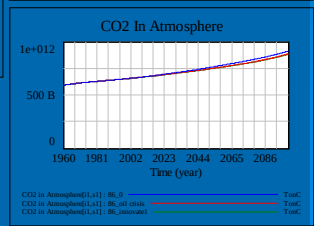

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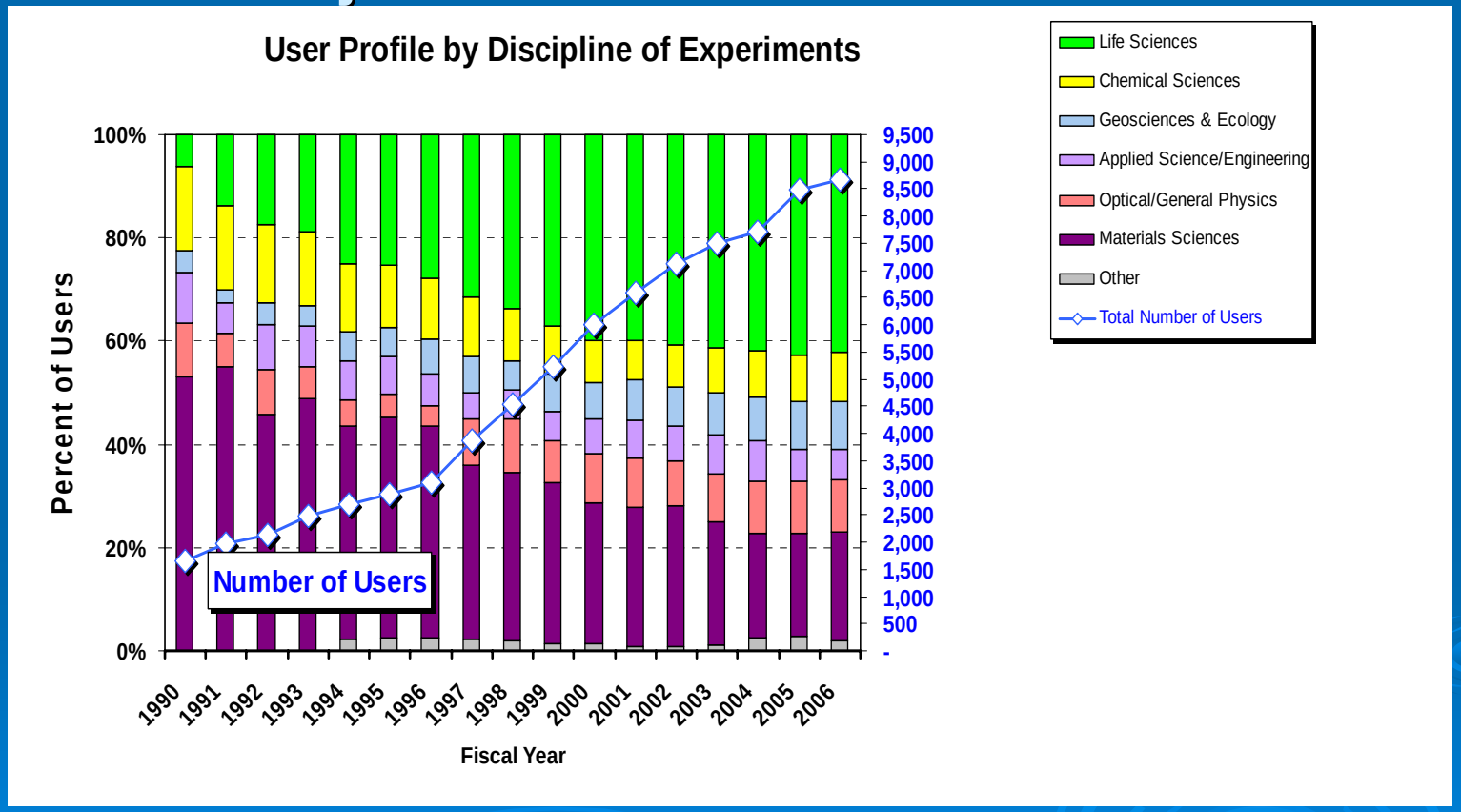
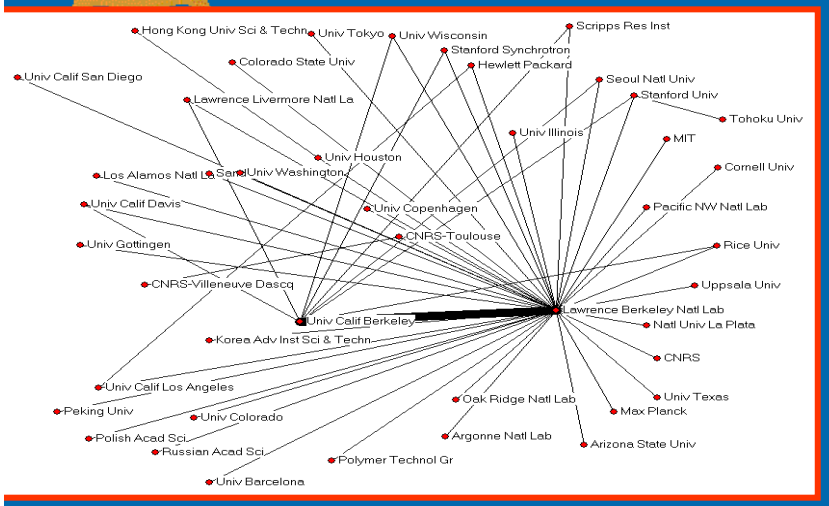
3. Progress in process metrics

Major Scientific User Facilities



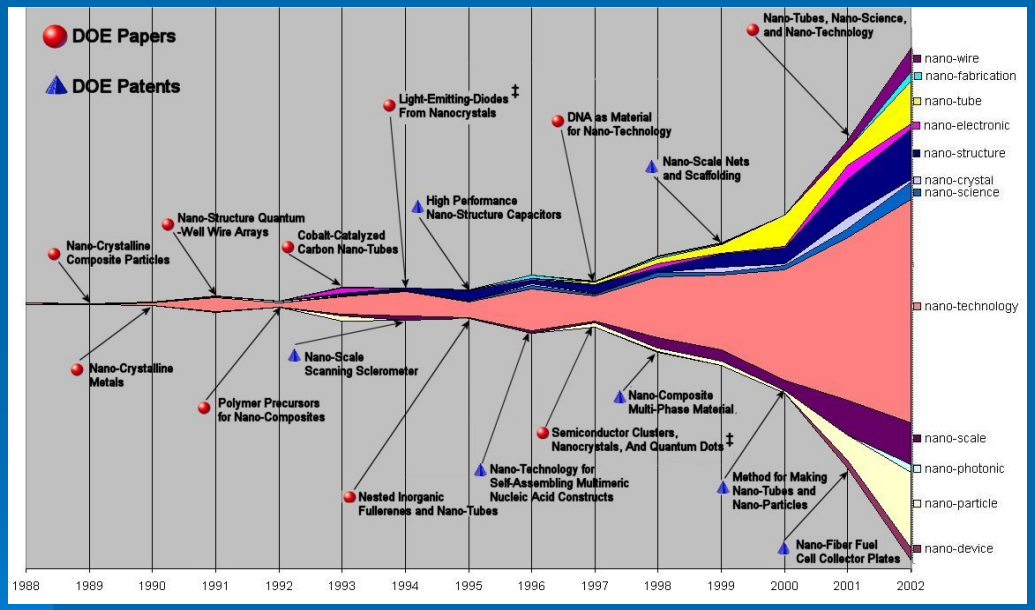
Considerable progress has been made on process metrics for science program management, but outcome/impact measures are still in their infancy.

4. Traditional tools are flawed



Lawrence Berkeley Lab's Core Nano Network, 2000-2004

Emergence of the Term "Nano" in Open Literature* Showing Representative DOE Papers and Patents

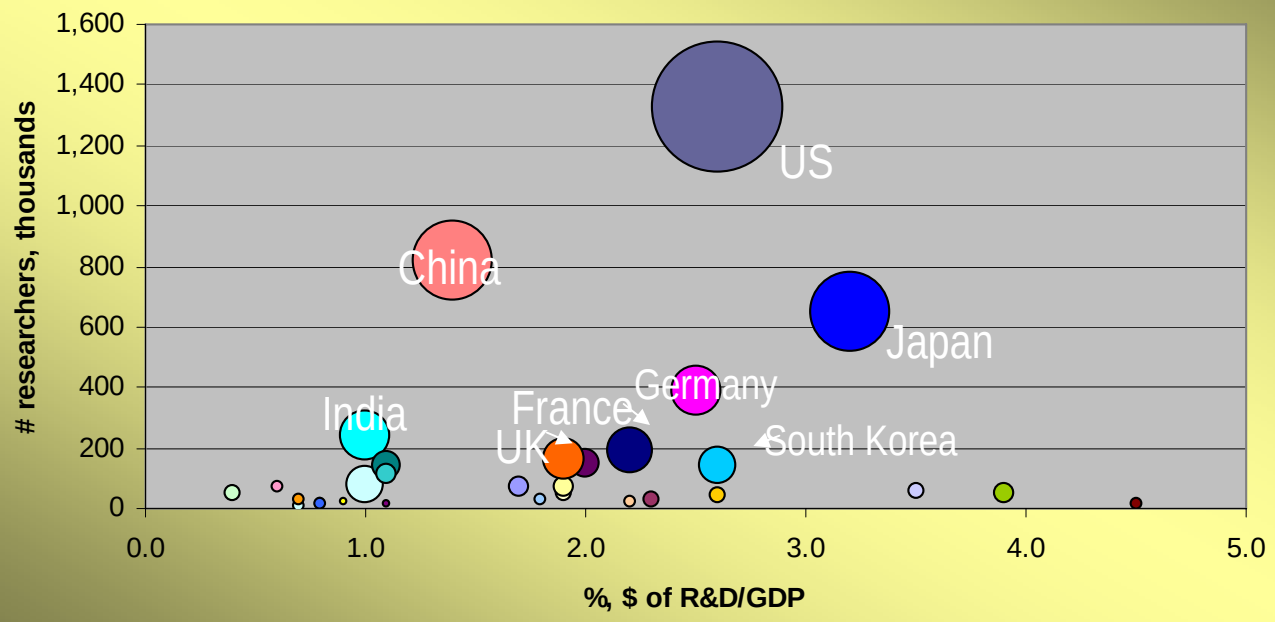


The traditional tools of R&D evaluation (bibliometrics, innovation indices, patent analysis, econometric modeling, etc.) are seriously flawed and promote seriously flawed analyses.

*Terms with at least 10 occurrences in at least one year. Width of color band indicates relative number of occurrences
‡ Papers identified by the Institute for Scientific Information as among the Top 25 Highly Cited Papers in Nanotechnology.

5. Limited government capacity for analysis

There is very little capacity within the Federal government to conduct science policy analysis and evaluation. This is caused by both resource constraints (total U.S. Federal investment in this area is less than $20 million/year) and an absence of a defined set of effective practices.



Global R&D Investment

6. Absence of Reliable Data

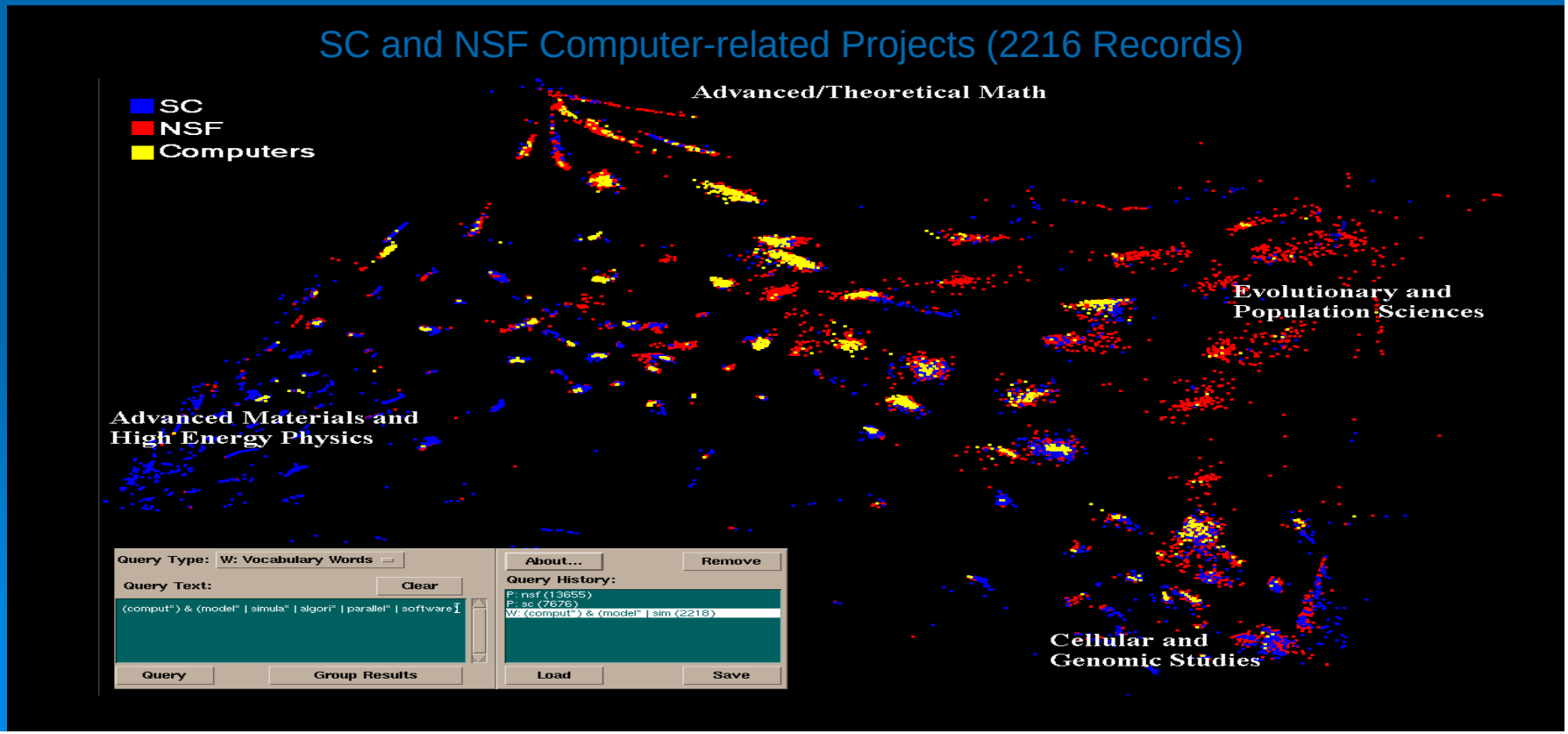
Complexity is Daunting

- U.S. Economy is $13.9 Trillion, w/50 States & 3,066 counties
- Federal Budget is $2.9 Trillion
- U.S. Federal R&D Investment - $136.9 Billion
- General Science Budget - $8.3 Billion
- $28.4 Billion to 1,227 colleges and universities for S&E
- 5.9 Million High Tech Workers
- 11 Million Scientists, Engineers and Technicians
- 4,807,000 scientists and engineers in US (2001)
- R&D data is typically found in journals, conference, workshops, pre-print servers, and scientific databases

Sources: OMB FY09 Budget Request
American Association of Counties – U.S. counties
CIA World Factbook (2006)
NSF SRS – budget (2007), academic funding (2005)
AeA, *Cyberstates 2008: A Complete State-by-State Overview of the High-Technology Industry* (2008)
http://www.dpeaflcio.org/programs/analyses/2002_sci_eng.htm, Dept for Professional Employees

7. Open to new rigorous tools

The scientific community is skeptical about the use of new decision support tools, but is open to a discussion, particularly one that centers on decision support tools that are scientifically rigorous and transparent.



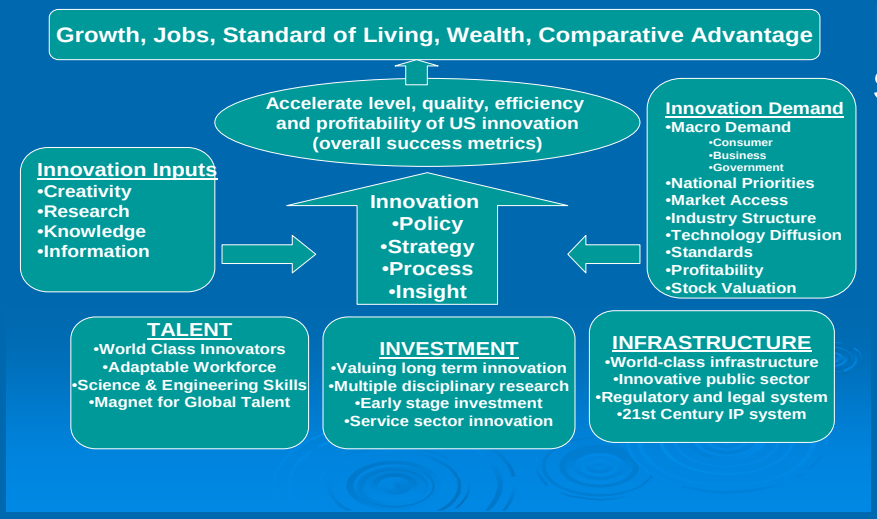
8. Confusion over key terms

A new generation of innovation metrics opens opportunities to apply new analytic tools to assess policy and strategic choices.

- **Growth Accounting**—economists will be able to better estimate the nation's productivity performance in terms of contributing factors and outputs.
- **Knowledge Economy**—composite knowledge indicators will improve investment decisions for R&D, education and capital resources.
- **Financial Reporting—**financial reports could provide a balanced scorecard of physical as well as intangible assets.
- **Valuation of Innovation**—business executives and financial markets could better value R&D activity and related intangibles, estimate financial results, improve long term stock market valuations and predict outcomes.
- **System Dynamics**—expanding the range of "real-time" innovation metrics would help build more robust systems dynamics models and policy simulations. .
- **General Purpose Technology (GPT)** — improved analysis of the strategic contribution of GPT's which set the stage for incremental innovation and have the inherent potential for pervasive application in a wide variety of industries.
- **Tech-led Regional Development and Clusters**—shift the emphasis from strengthening inputs to the innovation infrastructures toward improving the efficiency, rate and output of innovation.

9. No model of innovation

Figure 1. National Innovation Ecosystem



There is no agreed upon model of national innovation. This means that there is no agreement about what makes one system more innovative than another.

Highly performing innovation systems should have the following attributes:

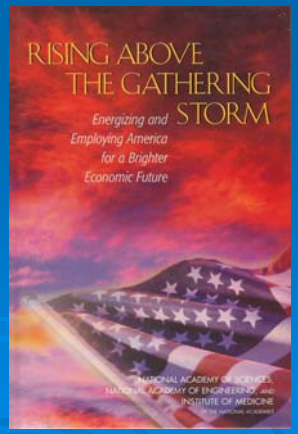
- *Competition for Resources*
  - (Money, Ideas, People, Facilities)
- *An open market place for ideas*
  - (Patents, Papers, Copyrights, IP)
- *Resources sufficient for system growth*
  - (People, Equipment, Money, Land, Energy)
- *Checks & Balances*
  - (Transparency, Multiple Funding Sources, External Review)

An absence of any of these will seriously impair the effectiveness & efficiency of any innovation system.

10. Misinformation and Advice

Because of the above, reports like the “Gathering Storm” cam provide flawed analyses and misguided advice to science policy decision makers.

- Existing “Innovation Indexes” suffer from a host of problems, primarily a lack of context, causality, and comparability.



Next steps

- Roadmap going through concurrence process – should be available by early November
- Roadmap implementation workshop in early December
- Interagency working groups to be formed around key themes

Types of data being used in Evaluation

- Data Issues
  - Units of analysis?
  - Massive data from heterogeneous sources
- Conceptual issues
  - Creation and transmission of knowledge
  - Complex interactions of actors
- Analytical issues
  - Outcome measures?
  - Counterfactuals?
- Empirical issues
  - Role of standard statistics?

Data questionnaire for SOSP registration

- Building an empirical platform for the science of science policy requires good data. Please provide an assessment of the current empirical basis along the following dimensions
  - Data existence
  - Data quality
  - Data documentation
  - Data accessibility
- Assign a score of 1 to 5 for each criterion. In each criterion, a low score suggests doing less of an activity, and a high score suggests doing more of an activity.

Data Input for SOSP workshop

	Data covering the universe exist [1 is strongly disagree/ impact; 5 is strongly agree]	**Data are high quality (e.g. have all key measures; measures reflect underlying concepts..)** [1 is strongly disagree/ impact; 5 is strongly agree]	**Data are well documented** [1 is strongly disagree/ impact; 5 is strongly agree]	**Data are available for use to the research and policy communities** [1 is strongly disagree/ impact; 5 is strongly agree]
"Input" Measures				
Generation of ideas (creativity)	o o o o o 1 2 3 4 5	o o o o o 1 2 3 4 5	o o o o o 1 2 3 4 5	o o o o o 1 2 3 4 5
Transmission of ideas (Scientific communication)	o o o o o 1 2 3 4 5	o o o o o 1 2 3 4 5	o o o o o 1 2 3 4 5	o o o o o 1 2 3 4 5
Source of ideas (STEM Workforce)	o o o o o 1 2 3 4 5	o o o o o 1 2 3 4 5	o o o o o 1 2 3 4 5	o o o o o 1 2 3 4 5
Funds for ideas (Federal funding)	o o o o o 1 2 3 4 5	o o o o o 1 2 3 4 5	o o o o o 1 2 3 4 5	o o o o o 1 2 3 4 5
Incentives for ideas (e.g. R&D tax credit)	o o o o o 1 2 3 4 5	o o o o o 1 2 3 4 5	o o o o o 1 2 3 4 5	o o o o o 1 2 3 4 5
Discovery to innovation infrastructure (institutions)	o o o o o 1 2 3 4 5	o o o o o 1 2 3 4 5	o o o o o 1 2 3 4 5	o o o o o 1 2 3 4 5
"Output Measures: Generation of Scientific Knowledge"				

Output Measures

	Data covering the universe exist [1 is strongly disagree/ impact; 5 is strongly agree]	**Data are high quality (e.g. have all key measures; measures reflect underlying concepts..)** [1 is strongly disagree/ impact; 5 is strongly agree]	**Data are well documented** [1 is strongly disagree/ impact; 5 is strongly agree]	**Data are available for use to the research and policy communities** [1 is strongly disagree/ impact; 5 is strongly agree]
"Output Measures: Generation of Competitive Economy"				
Creation of Firms	o o o o o 1 2 3 4 5	o o o o o 1 2 3 4 5	o o o o o 1 2 3 4 5	o o o o o 1 2 3 4 5
Growth of Firms	o o o o o 1 2 3 4 5	o o o o o 1 2 3 4 5	o o o o o 1 2 3 4 5	o o o o o 1 2 3 4 5
Competitiveness of firms	o o o o o 1 2 3 4 5	o o o o o 1 2 3 4 5	o o o o o 1 2 3 4 5	o o o o o 1 2 3 4 5
Creation of jobs	o o o o o 1 2 3 4 5	o o o o o 1 2 3 4 5	o o o o o 1 2 3 4 5	o o o o o 1 2 3 4 5
Creation of high wage jobs	o o o o o 1 2 3 4 5	o o o o o 1 2 3 4 5	o o o o o 1 2 3 4 5	o o o o o 1 2 3 4 5
Discovery to innovation infrastructure (institutios)	o o o o o 1 2 3 4 5	o o o o o 1 2 3 4 5	o o o o o 1 2 3 4 5	o o o o o 1 2 3 4 5
"Data infrastructure: "				
Micro level links between input measures and output of scientific knowledge	o o o o o 1 2 3 4 5	o o o o o 1 2 3 4 5	o o o o o 1 2 3 4 5	o o o o o 1 2 3 4 5
Micro level links between input measures and competitive economy	o o o o o 1 2 3 4 5	o o o o o 1 2 3 4 5	o o o o o 1 2 3 4 5	o o o o o 1 2 3 4 5

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Advancing the Science of Evaluation

- Statistical component
  - Many SRS surveys being redesigned
  - BRDIS
- Investigator Initiated Research
  - Three Solicitations – two sets of awards
  - Awards of interest to this group

Statistical Component: Survey Redesign

Genesis of the Survey of Industrial R&D

- ***. . .*** *The Foundation shall continue to make comprehensive studies and recommendations regarding the Nation's scientific research effort and its resources for scientific activities, including facilities and scientific personnel, and its foreseeable scientific needs, with particular attention to the extent of the Federal Government's activities and the resulting effects upon trained scientific personnel.*
  - Executive Order 10521 - Administration of scientific research by agencies of the Federal Government *(March 17, 1954)*

Genesis of the Survey of Industrial R&D (cont.)

- To enact this order, NSF developed a series of coordinated surveys of the workforce and research activities in industry, government agencies, colleges and universities, and other organizations conducting or supporting research.
  - Establishment surveys (ex. Survey of Industrial Research and Development, Survey of Federal Funds for Research and Development)
  - Surveys of individuals (ex. Survey of Earned Doctorates)

Inputs to First NSF SIRD

- Harvard Business School study of industry R&D
  - Many definitions and instructions were borrowed from this survey of 191 firms in 1952
- Industry Survey Steering Committee (NSF/BLS)
- Department of Defense
- Industrial Research Institute
- National Association of Manufacturers
- Industry Advisory Committee

Motivation for Redesign

- Changing Survey Context
- National Academies Committee on National Statistics (CNSTAT) recommendations from its review of SRS' R&D Statistics Program in 2005
- Resources were available at NSF and Census to support a redesign effort

Survey Context: Then and Now

1950s

- Government largest source of R&D $$$
- Business largest basic research performer
- Manufacturing economy
- Large companies dominate R&D $$$
- Domestic focus
- Focus on in-firm S&T resources (central research labs)

2000s

- Business largest source of R&D $$$
- Academia largest basic research performer
- Services economy
- Large companies not as dominant
- Global focus
- Increased leveraging of S&T resources outside the firm

CNSTAT Recommendations

- It is time to implement another major redesign of the Industry R&D Survey. SRS should take the lead in the work on the industrial survey, using the tools of the (Census) interagency agreement, the oversight of a high-quality methodological staff, and the input of highly qualified outside experts.
- SRS and the Census Bureau should resume a program of field observation staff visits to examine record-keeping practices and conduct research on how respondents fill out the forms; and to determine if they can report by more specific R&D categories.

CNSTAT Recommendations (cont.)

- NSF should examine the costs and benefits of administering the Survey of Industrial R&D at the line of business level.
- NSF should again develop a panel of R&D experts of data users and R&D performers (including R&D executives) who are most aware of trends in the structure and performance of R&D.
- The editing system should be redesigned so that the current problems of undocumented analyst judgment and other sources of potential error can be better understood and addressed.

Survey Redesign Process

- Evaluate content:
  1. Identify data user needs and priorities
  2. Assess availability of R&D data
- Evaluate current survey operations and methodology
- Define new content and methods
- Implement!

Current Strategy

- Adopt a modular survey structure
- Collect both domestic and global data to address multinational enterprises
- Address small companies with a different survey focused on innovation
- Evaluate new techniques for producing analytical estimates using existing statistical data (ex. finer geographic detail)

Rationale for Modular Approach

- Priority items identified by data users span a variety of subject matter areas
- The knowledge needed to answer R&D-related questions in these various subject matter areas may be housed in different organizations within a company according to respondent debriefings, recordkeeping interviews, and meetings with industry experts

Investigator Initiated Component Solicitations

Awards from Solicitation I

- **Human capital development and the collaborative enterprise:**
- **Returns to international knowledge flows**
- **Creativity and innovation**
- **Knowledge production system**
- **Science policy implications**

Awards from Solicitation II

- Describing the Role of Firms in Innovation
- Measuring and Tracking Innovation
- Measuring and Evaluating Scientific Progress
- Advancing Understanding of Collaboration and Creativity
- Knowledge sharing and creativity
- Implementing Science Policy

Awards of interest to this group

- Linking Government R&D Investment, Science, Technology, Firms and Employment: Science & Technology Agents of Revolution (Star) Database (Lynne Zucker and Michael Darby, University of California, Los Angeles)
  - Data creation with links from government investment in R&D through the path of knowledge creation, its transmission and codification; then commercialization
    - NSF, NIH, DoD and DoE grants,
    - All journal articles and citations, high-impact articles, highly-cited authors, UMI ProQuest Digital Dissertations
    - US utility patents (complete/parsed/cleaned),
    - Venture capital, IPOs, web-based firm data, and links to major public firm databases via ticker symbols and/or CUSIP numbers.
    - Concordance linking STAR IDs to the IDs in the Census Bureau's Integrated Longitudinal Business Database (ILBD) and Longitudinal Employer-Household Dynamics (LEHD) program, Census data, for use within the Census Research Data Centers.
  - Dissemination
    - 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

Figure 1 – Major Features of the U.S. National Innovation System in the STAR Database: Policy, Innovation, Institutional Processes, and Economic Growth

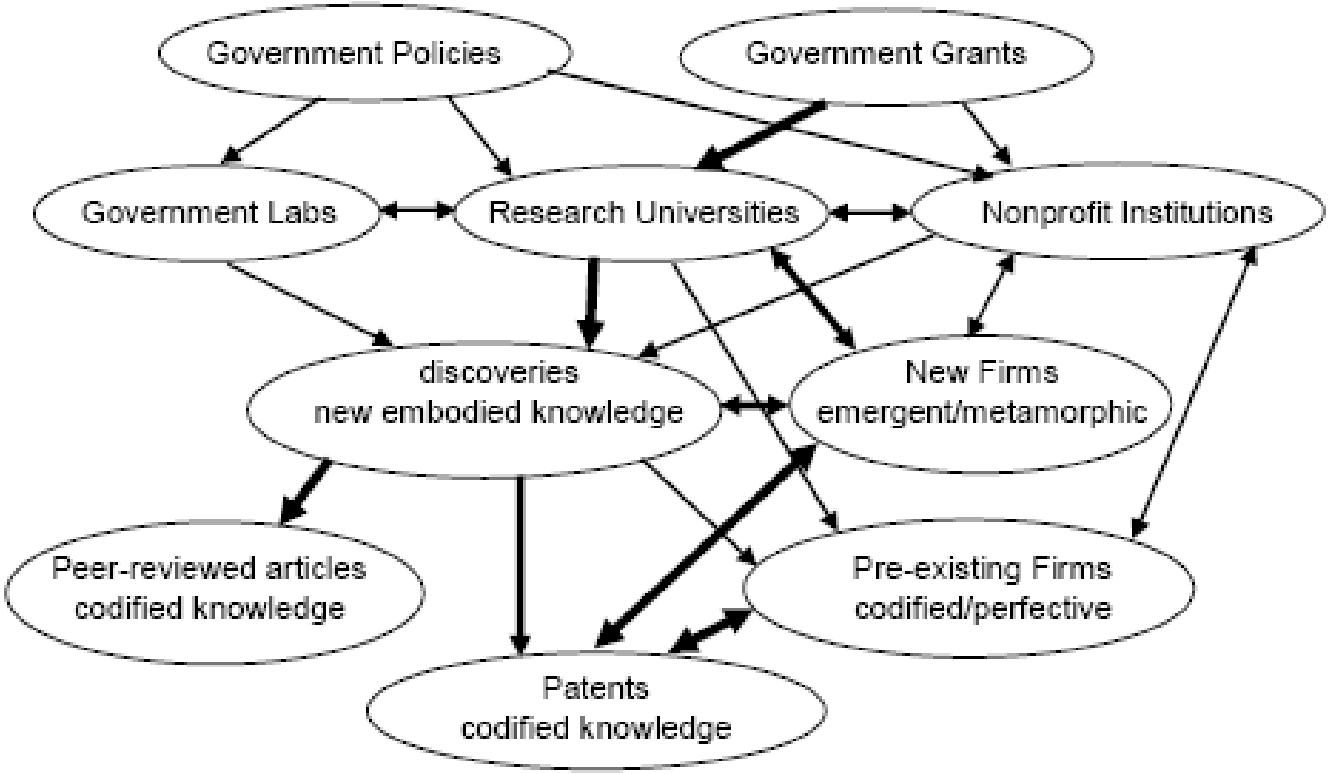
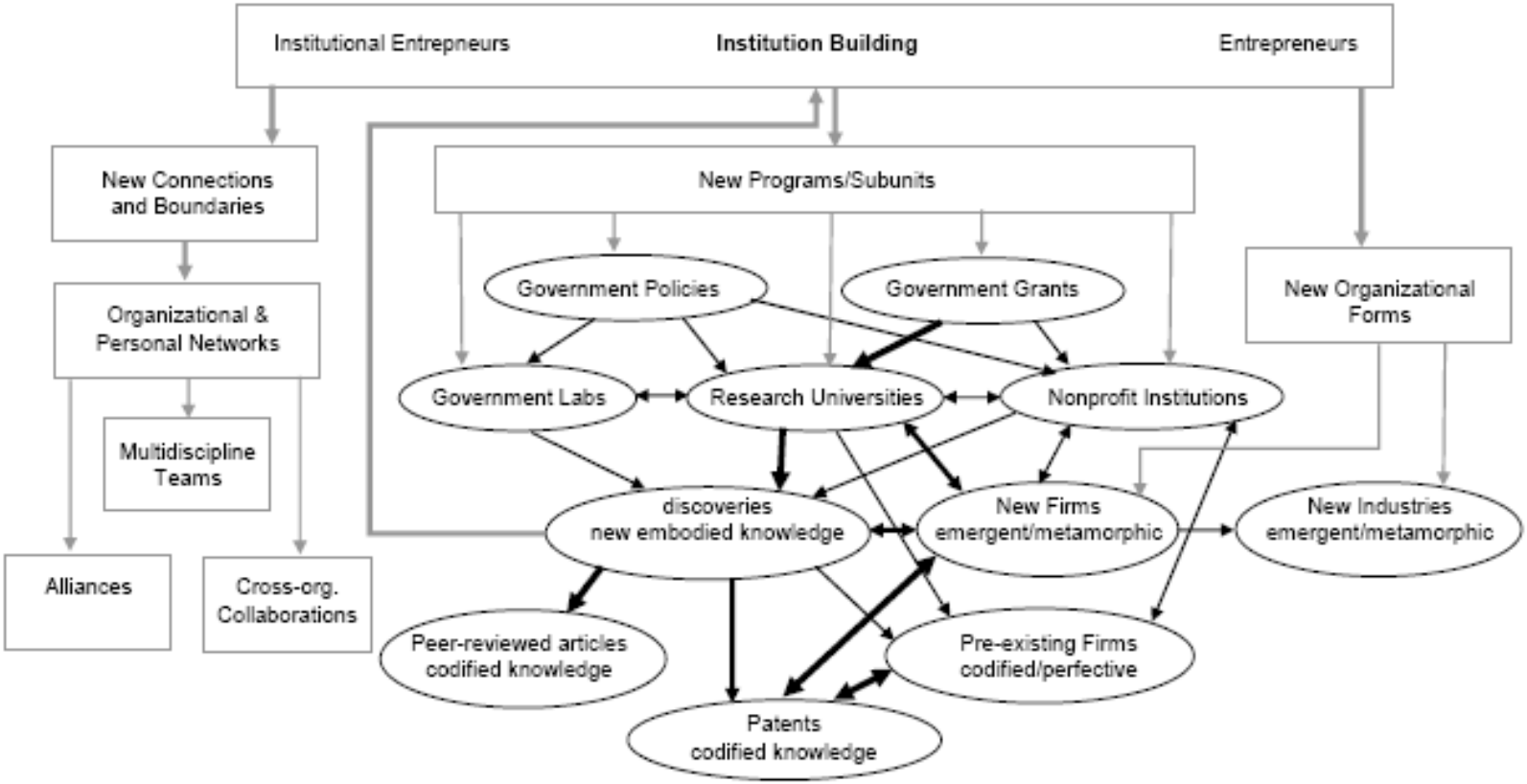


Figure 2 – Institutional Processes in Tandem with Knowledge Creation, Transmission and Use



Note: grey boxes and arrows denote institutional processes

Awards of interest to this group

- A Social Network Database of Patent Co-authorship to Investigate Collaborative Innovation and its Economic Impact (Lee Fleming, Harvard University)
  - Develops a freely available social network database built from all U.S. patent co-authorships since 1963; Complements NBER patent database
  - Unit of analysis at the individual inventor and aggregate levels including organizational, regional, and technological
  - 1) refines inventor identification by encouraging inventors to check the identification algorithm,
  - 2) develops currently unavailable social network variables,
  - 3) makes the relational data easily available via the Harvard-MIT Dataverse infrastructure
  - 4) develops real time capability to visualize patent co-authorship networks.

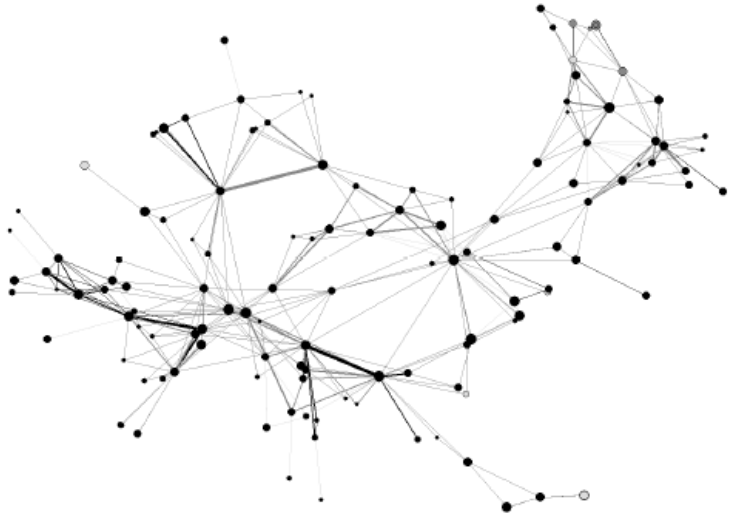


Figure 1: Bosch carburetor patents, circa 1980 (unpublished, developed with Dan Snow and Venkat Kuppuswamy). Note the difference with Figure 3, in that Bosch is much more collaborative. Nodes represent inventors and node size corresponds to the number of patents. Black nodes represent inventors who work in physical technologies, dark grey nodes represent electronic technologies, and light grey nodes represent inventors in both technologies. Tie width corresponds to the number of co-authored patents. Light grey ties represent later ties, black ties earlier ties, and dark gray ties intermediate

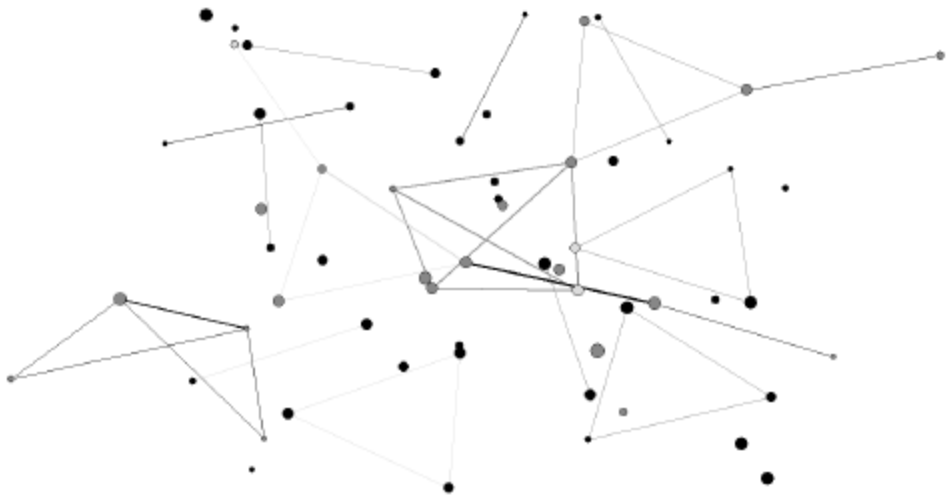


Figure 2: Ford carburetor patents, circa 1980 (unpublished, developed with Dan Snow and Venkat Kuppuswamy). Ford inventors are much more isolated and less collaborative than Bosch inventors illustrated in Figure 1.

Awards of interest to this group

- Modeling Productive Climates for Virtual Research Collaborations (Sara Kiesler, Carnegie Mellon University and Jonathon Cummings, Duke University)
  - Unit of analysis is project-based research collaboration involving researchers from different institutions
  - Studies the institutional environments of a sample of projects that were supported by the National Science Foundation.
  - Examines importance of a productive climate for distributed research collaboration,
  - Traces the linkages among productive climate and the institutional environments of these collaborations.
  - => better metrics for measuring and predicting performance and innovation in collaborations.

Index	Items
Knowledge outcomes ('ideas')	Started new field or area of research; developed new model or approach in field; came up with new grant or spin-off project; submitted patent application; presented at conference or workshop; published article(s), book(s), or proceeding(s); recognized with award(s) for contribution to field(s). Alpha = .63 (7 items)
Tools outcomes ('tools')	Developed new methodology; created new software; created new hardware; generated new dataset; generated new materials; created data repository; created website to share data; created collaboratory; created national survey; developed new kind of instrument; created online experiment site. Alpha = .65 (11 items)
Training outcomes ('people')	Grad student finished thesis or dissertation; grad student/post-doc got academic job; grad student/post-doc got industry job; undergrad/grad student(s) received training; undergrad(s) went to grad school. Alpha = .70 (5 items)
Outreach outcomes ('people')	Formed partnership with industry; formed community relationship through research; formed collaboration with researchers; established collaboration with high school or elementary school students; established collaboration with museum or community institution; established collaboration with healthcare institution. Alpha = .45 (6 items)

Table 1. Project outcomes studied in Cummings & Kiesler, 2007.

Awards of interest to this group

- Dynamics of Creativity and Innovation in Cyber-enabled Scientific Commons (Levent Yilmaz, Auburn University)
  - Agent simulation models
  - (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.
  - Creates 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.

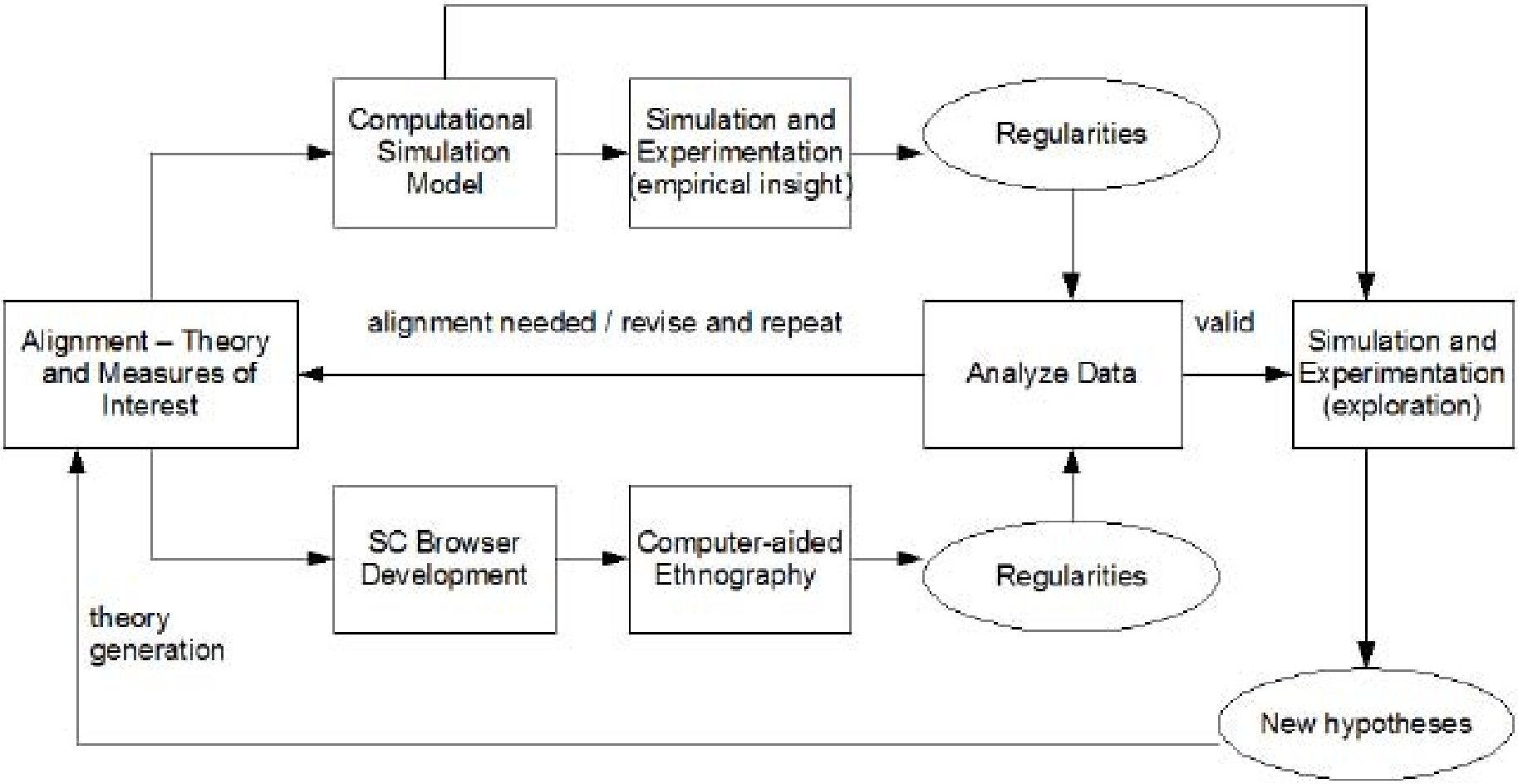


Figure 2: Research Strategy

Awards of interest to this group

- Integrating Social and Cognitive Elements of Discover and Innovation (Chris Schunn, University of Pittsburgh)
  - Examines video data collected from a recent highly successful case of science and engineering, the Mars Exploration Rover. 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).

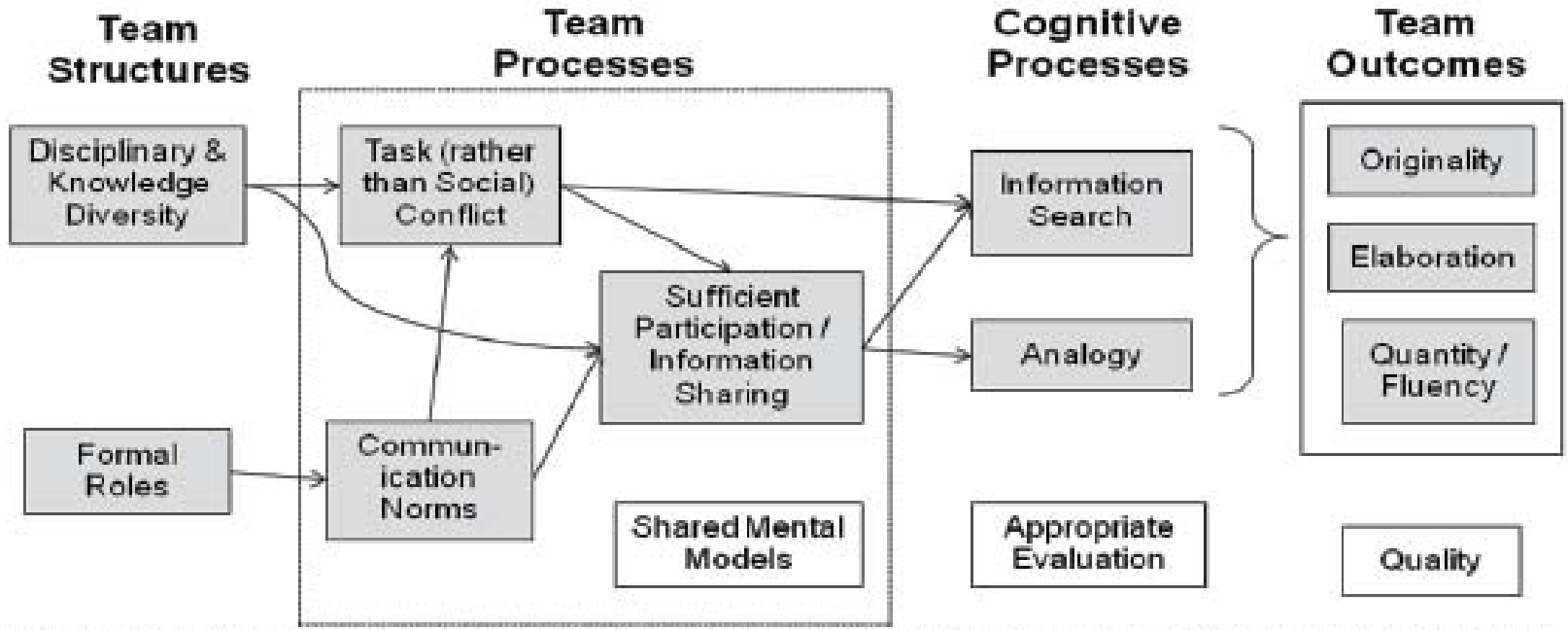


Figure 1: Hypothesized Social-Cognitive Pathways of Team Divergent Thinking

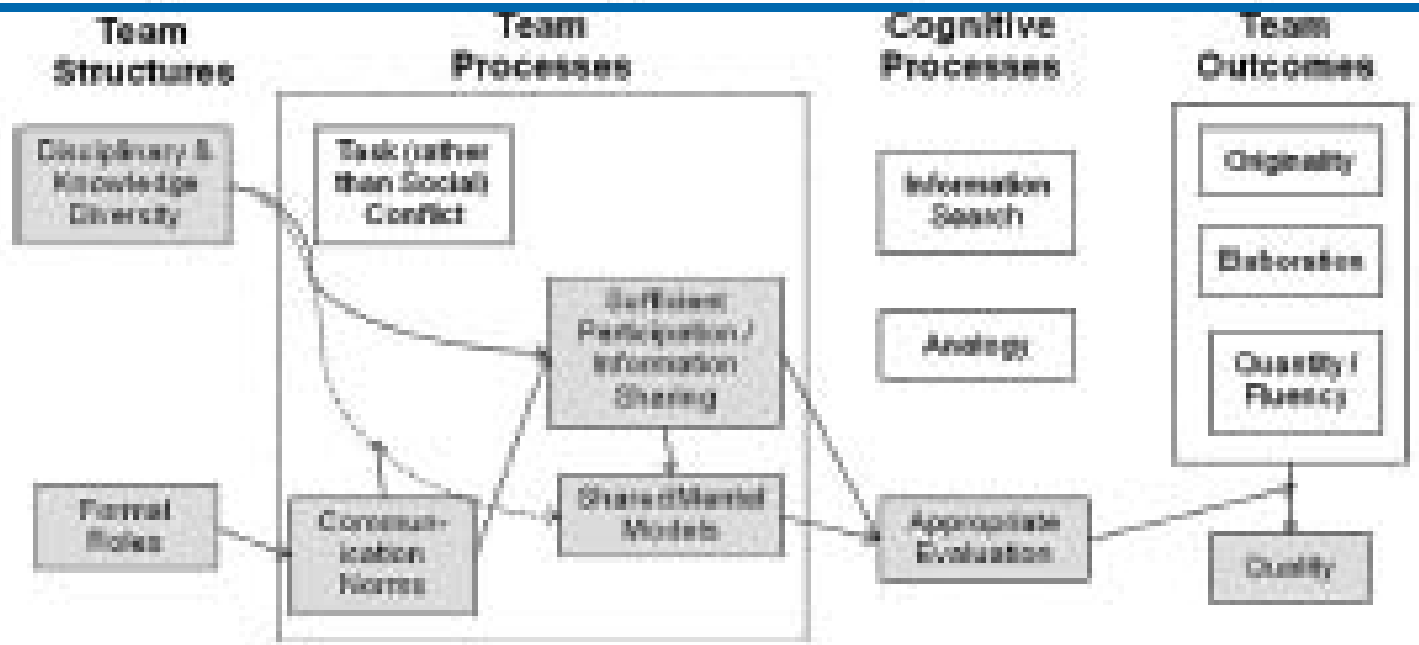


Figure 2: Hypothesized Social-Cognitive Pathways of Team Convergent Thinking

Solicitation III

- Demonstration projects on Organizations and Innovation
- Visualization (drawing particularly on visual analytics)
- International Collaborations

SMART Board
government, security, minister
china, government, country
president, security, cooperation
government, people, minister
china, country, economic
people, government, president
government, united, north
president, people, party
north, korea, government
security, government, people
LIVE NEWS
IN-SPIRE

SciSIP Milestones

- **Longer term:**
  - An evidence-based understanding of the impacts of the S&E enterprise
  - A capacity to better nourish and harness the capabilities of the national STEM workforce
  - The development of a Community of Practice

Thank you!

Comments and questions invited.

For more information please contact:

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