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Informing public policy on science and innovation: the Advanced Technology Program's experience

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Abstract The Advanced Technology Program (ATP) collected a unique source of data from highly innovative firms beginning in 1993. These data follow the OECD's guidelines for collecting innovation data and provide important insights for understanding the innovation process within firms. Although the data are not representative of the population of firms, there is sufficient number of firms in the dataset to test hypotheses and to provide a starting point for calls for innovation metrics. Because of the confidential nature of the data, ATP worked with the National Opinion Research Center (NORC) to create a Data Enclave so that researchers could remotely access the ATP data in a secure environment. To initiate the use of ATP data in the Data Enclave, the ATP program funded researchers to undertake research projects that use ATP data. Other organizations have joined the Data Enclave, including the Department of Agriculture and the Kauffman Foundation.

Keywords Innovation measurement · Data Enclave · Advanced Technology Program

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1 Measuring innovation

Many highly respected researchers studying the impact of public policy on innovation have advocated significant increases in the collection and analysis of data. Jaffe (2008) in his keynote address to the National Science Foundation's Workshop on Advancing Measures of Innovation in June 2006 concluded that:

> Developing the *Science of Science Polic*y will require data collection and analysis related to the processes of innovation and technological change, and the effects of government policy on those processes.

Other recent reports have similarly cited the need for additional innovation metrics to understand the value added to customers and firms that result from innovation. For example, the Oslo Manual (OECD 2005) states, "The ability to determine the scale of innovation activities, the characteristics of innovating firms, and the internal and systemic factors that can influence innovation is a prerequisite for the pursuit and analysis of policies aimed at fostering technological innovation."

Jack Marburger, the President's science advisor between 2001 and 2008, initiated the recent Science of Science Policy initiative in his editorial in the *American Association for the Advancement of Science* (or *AAAS*) Science magazine (Marburger 2005). He describes his goal as follows (Marburger 2007):

> We need models—economists would call them microeconomic models—that simulate social behaviors and that feed into macroeconomic models that we can exercise to make intelligent guesses at what we might expect the future to bring and how we should prepare for it.

The Department of Commerce (DOC 2008) brought together business leaders to recommend actions for measuring innovation in the U.S. In their report, *Innovation Measurement*: *Tracking the State of Innovation in the American Economy,* they stated that:

> To encourage more research by non-government researchers, the Advisory Committee recommends that the government encourage innovation research by making public data more transparent through the use of data-tagging or similar methods of making data more use-friendly and by improving access to data through the creation of more public use data files.

Table 1 provides a summary of selected initiatives to measure innovation. These initiatives recognize the importance of innovation for economic growth as well as the difficulty in measuring and understanding innovation.

These renowned researchers have concluded that until we have appropriately collected and analyzed a critical mass of data about the inputs, processes, outputs and outcomes of technology development, we shall not sufficiently understand the underlying mechanisms to be able to consistently produce desired economic and societal effects with our public policy. Thus, this paper has two goals. The first is to describe the data collected by the Advanced Technology Program (ATP) and how it could be used to inform the Science of Science Policy Initiative and innovation measurement. The second is to describe the Data Enclave, initiated with funding from ATP, which provides researcher access to confidential business datasets in a secure, yet user-friendly and collaborative environment.

Many countries have Community Innovation Surveys that are conducted on a regular basis (Cooper and Merrill 1997 and OECD 2005). The United States has experimented with innovation surveys. The National Science Foundation conducted a pilot national innovation

Table 1 A summary of selected government initiatives to measure innovation

Sponsor	Initiative	Description
Congress	COMPETES Act (P.L. 110-69) (August 2007)	Establishes a President's Council on Innovation and Competitiveness. In addition to policy monitoring and advice, the Council's duties include "developing a process for using metrics to assess the impact of existing and proposed policies and rules that affect innovation capabilities in the United States" as well as "developing metrics for measuring the progress of the Federal government with respect to improving conditions for innovation, including through talent development, investment, and infrastructure development."
Office of Science and Technology Policy	Science of Science Policy (SoSP) Interagency Task Group (OSTP 2008)	Established in October 2006, the task group is analyzing federal and international efforts in science and innovation policy, identifying tools needed for new indicators and charting a strategic road map to improve theoretical frameworks, data, models, and methodologies.
National Science Foundation	Science of Science and Innovation Policy (SciSIP)[1]	Established in 2006, the initiative is expected to develop the foundations of an evidence-based platform from which policymakers and researchers may assess the nation's S&E enterprise, improve their understanding of its dynamics, and predict its outcomes. The research, data collection, and community development components of SciSIP's activities will: • develop theories of creative processes and their transformation into social and economic outcomes; • improve and expand science metrics, datasets, and analytical tools; and • develop a community of experts on SciSIP.
National Science Foundation	Workshop on Advancing Measures of Innovation: Knowledge Flows, Business Metrics, and Measurement Strategies (2006)	The workshop was in response to the challenge set forth by Dr. John H. Marburger III, the president's S&T adviser, for better data, models, and tools for understanding the U.S. S&E enterprise. A number of strategies for data development were discussed: • survey-based methods, • data linking and data integration, • nonsurvey-based methods (such as mining of administrative data), and • using case studies and qualitative data. These diverse strategies are not mutually exclusive.
OECD	Blue Sky Forum (OECD 2007)	The forum discussed the development of new and better indicators of science, technology, and innovation and developed a synthesis of findings toward an agenda for the next decade.
Department of Commerce	Innovation Measurement, Tracking the State of Innovation in the American Economy (2008)	This Committee of business and academic leaders was charged to develop new and improved measures of innovation in three areas: how innovation occurs in different sectors of the economy, how it is diffused across the economy, and how it affects economic growth.

survey in 1994 and an Information Technology Innovation Survey in 2001. In 2008, they added an innovation component to their Survey of Industrial Research and Development and renamed the survey. It is now called the Business R&D and Innovation Survey

[1] Science of Science & Innovation Policy Newsletter, Volume 1, issue 1, October 2008, http://www.nsf.gov/sbe/scisip/scisipnews1.pdf. Accessed 7 December 2008.

(BRDIS).[2] However the US does not conduct a comprehensive national innovation survey, similar to the Community Innovation Survey. One of the recommendations in the Department of Commerce's report on innovation measurement is to "create a supplemental innovation account for the NIPAs (National Income and Product Accounts) in order to expand the categories of innovation inputs and allows these inputs to be tracked as they flow between industries." The ATP data are a unique source of data that could be used to think about a Community Innovation Survey for the US as well as to examine whether companies can provide quantitative data needed to construct an Innovation Satellite Account.

Among it many goals, ATP sought to collect a body of data that would contribute in a significant and meaningful way to the understanding of innovation and technology development. While these data were collected for ATP awardees (and in some cases, ATP applicants), they represent a set of exceptionally innovative companies. Analysis of these data can be used to understand the characteristics of innovative companies and to test hypotheses about the role of government funding and the structure of innovative projects within companies. These data provide an initial look at innovation that could set the stage to construct an innovation survey in the United States.

Beginning in 1993, ATP collected data to evaluate the impact of the program and to inform public policy. Data were collected from a variety of stakeholders using a variety of survey and data collection methodologies. In analyzing the data, ATP faced a major challenge in having to use external researchers. While these researchers added fresh and broad theoretical perspectives, to protect the confidentiality of the business data, the researchers had to come to the NIST campus. This necessity created at least two major limitations for the research. First, it severely limited the impact of the data on the public policy debate by limiting the number of researchers who could do research. Second, it limited the value of the data to the scientific community. Researchers without access could not replicate scientific analyses based on the data. Researchers could not collaborate on concepts and ideas when some did not have access. They could not train junior researchers and students on how to work with business data. And they could not provide feedback to data producers on data quality (Lane 2007).

In sum, the experience of ATP reveals that collecting and analyzing data are not enough. It is also crucial to provide data access to a broad base of researchers, to develop a community of practice investigating the data, and to provide a mechanism that will support the ideal of transparent analyses that are both generalizable and replicable. Section 2 describes the Advanced Technology Program, the surveys collected as part of the ATP program, and findings from these surveys. Section 3 describes a Data Enclave that allows researchers to remotely access ATP data in a secure and confidential way (Lane and Shipp 2007). Section 4 concludes the paper with a brief summary of policy issues currently being investigated with these data.

2 The Advanced Technology Program (ATP)

ATP is one of three extramural programs at the National Institute of Standards and Technology (NIST). Through ATP the U.S. Congress promoted innovation in the United States by stimulating companies to undertake high-risk, high-reward research and development (R&D) projects. The goal of these projects is to solve difficult technical problems and create significant industry-wide benefits where the potential benefits to the nation

[2] http://www.nsf.gov/statistics/srvyindustry/about/brdis/start.cfm. Accessed 5 December 2008.

Table 2 Description of the Technology Innovation Program (TIP)

The America Creating Opportunities to Meaningfully Promote Excellence in Technology, Education, and Sciences (COMPETES) Act, Pub. L. 110-69, was enacted on August 9, 2007, to invest in innovation through research and development, and to improve the competitiveness of the United States. Section 3012 of the COMPETES Act established TIP for the purpose of assisting U.S. businesses and institutions of higher education or other organizations, such as national laboratories and nonprofit research institutions, to support, promote, and accelerate innovation in the United States through high-risk, high-reward research in areas of critical national need. High-risk, high-reward research is research that:
• has the potential for yielding transformational results with far-ranging or wide-ranging implications;
• addresses critical national needs that support, promote, and accelerate innovation in the United States and is within NIST's areas of technical competence; and
• is too novel or spans too diverse a range of disciplines to fare well in the traditional peer-review process.
This statute abolishes the Advanced Technology Program (ATP), but allows for continued support for previously awarded projects and the 56 awards funded starting in FY 2007.
Features
The major features of the Technology Innovation Program are established in the authorizing legislation. Some highlights:
• TIP is to make cost-shared awards of no more than 50 percent of total project costs to high-risk R&D projects that address critical national and societal needs in NIST's areas of technical competence.
• Projects may be proposed either by individual, for-profit companies or by joint ventures that may include for-profit companies, institutions of higher learning, national laboratories or non-profit research institutes, so long as the lead partner is either a small or medium-sized business or an institution of higher learning.
• Awards are to be limited to no more than $3 million total over three years for a single-company project or no more than $9 million total over five years for a joint venture.
• TIP may not provide funding to any business that is not a small or medium-sized business, though those businesses may participate in a TIP funded project.
For more information about this program, see: http://www.nist.gov/tip/

exceed the benefits to the innovating company. Without outside intervention, companies tend to under-invest in these projects, and as a result, society and the national economy suffer as beneficial technologies either fail to reach the market or are slow in development. Congress sought to address this market failure through creation of the ATP, and with the program's first congressional appropriation in 1990. By sharing the research costs, ATP endeavored to foster the development and subsequent commercialization of enabling technologies where the benefits to society are likely to exceed the perceived benefits to the innovating companies.

The America COMPETES Act (PL 110-69, signed on Aug 9, 2007) created a new Technology Innovation Program (TIP) at NIST. TIP was established "to support, promote, and accelerate innovation in the United States through high-risk, high-reward research in areas of critical national need." This statute abolishes the Advanced Technology Program (ATP), but allows for continued support for previously awarded projects and the 56 awards funded starting in 2007. TIP staff is developing a new set of surveys to capture innovation funded under TIP. Table 2 describes the new Technology Innovation Program.

ATP collected data on innovation and company characteristics through a system of survey instruments. Three components of the ATP system of surveys are relevant to this article:

- The Business Reporting System (BRS)
- The Survey of Applicants
- The Survey of Joint Ventures

The heart of the surveys is the BRS that provides longitudinal data on ATP companies. The latter two surveys complement the BRS surveys. Each survey is described in detail below.

2.1 The Business Reporting System (BRS)

ATP started collecting data in 1993 through its BRS and, under current plans, will continue data collection through 2010. This annual data collection effort conforms to many of the Oslo Manual's criteria for innovation data (OECD 2005). Specifically, these data meet the criteria that:

- the survey questions be based on economic theory,
- the data explore the role of linkages with other firms and institutions in the innovation process, and
- the questions capture data on critical theoretical concepts such as organizational innovation and marketing innovation.

These data are collected at regular intervals (annually during the project and biannually after project close) as the firm is in the process of developing technological innovations. As a result, ATP surveys represent a unique and rich data source for understanding the interaction of science policy and innovation, and thus an important data source for informing the Science of Science Policy initiative.

There are some significant limitations to note about the ATP BRS data. First, the data are collected from ATP awardees and therefore are not representative of US companies in general. Companies unable to produce cutting edge research and those unable to meet ATP standards have been excluded. Second, the surveys primarily focus on high-risk technology development in the creation of innovative processes and products. Very little attention is given to the lower risk research and innovations of the companies studied. Thus while the data may or may not speak to the innovation process in all firms, the ATP data do provide critical insight into the innovation black box by exploring many facets of innovation, especially in arenas likely to drive new markets.

ATP's BRS surveys collect data on multiple facets of the innovation process. First, several questions focus on the program effects that result from providing awards to companies to undertake high-risk innovative research that has the potential to broadly affect the economy and society. These include:

- the research direction that project would have taken without funding,
- the attraction of additional funding,
- the acceleration of technology development,
- the engagement in strategic alliances and collaborations,
- changes in the technology infrastructure (such as linkages between or within sectors),
- the effect on the company's strategic business planning, and
- the impact of the award on the credibility of the company and the technology.

Additional areas in the surveys fill out the picture on the innovation process. A second area focuses on the companies' plans to commercialize their developing technology and bring their technology to market with a series of questions to identify commercial applications of the technology. A third area focuses on capturing information about knowledge spillovers. A fourth area collects data on collaborative relationships to discover the extent and purpose of collaboration, how well the collaborative relationships were working, and who was collaborating with whom. Finally, the survey also collects data on employment, competitive standing, leveraging of research funding, perceived risk, and other related topics. Since ultimately the goal for the Science of Science Policy is to quantify these relationships among these factors in measuring and managing innovation, the ATP data represent an important source.

In addition to the BRS surveys, ATP also conducted two special topic surveys to gather additional insight—The Survey of ATP Joint Ventures and The Survey of ATP Applicants. Unlike the annual BRS surveys, these special topic surveys were conducted less frequently.

2.2 The Survey of ATP Applicants

The Survey of ATP Applicants was conducted for the grant competitions in 2000, 2002, and 2004. These surveys gathered data on satisfaction with the ATP application process ("customer satisfaction"), characteristics of the ATP applicants, and research program effects for awardees and non-awardees. At the time, ATP was one of the few programs (if not the only one) to systematically and regularly survey organizations that did not receive financial support. All for-profit companies applying to ATP were included in the surveys; other organizations, such as universities and non-profits, were excluded. The Survey of ATP Applicants was divided into seven major sections:

- Reasons for applying to ATP
- Comparison of ATP project with the firms' typical R&D project
- Anticipated value from the proposed project
- Other characteristics of the proposed project
- Proposal preparation and review (including "customer satisfaction")
- Expenditures for the line of research represented by ATP project
- Company characteristics.

2.3 The Survey of ATP Joint Ventures

The Survey of ATP Joint Ventures was conducted in 2003 to provide information on characteristics and outcomes of nearly 400 companies participating in 142 R&D joint ventures (JVs) funded by ATP between 1990 and 2004. The survey was divided into seven major sections:

- Joint venture motivation and formation
- JV project characteristics including risk and time horizon profiles
- JV structure and governance
- JV personnel and company history in collaborative work
- Outcomes of the joint venture
- JV partner company profiles
- Company characteristics.

A summary of findings from these surveys is presented in the following sections.

2.4 Analytical work using ATP surveys: informing public policy

Before proceeding to specific findings from the three survey efforts described above, we highlight results that are consistent throughout all of ATP's data collection efforts. These general findings have strong implications for the public policy of innovation.

The first pervasive result is that selection criteria of innovation and high technical risk are positively correlated with outputs and outcomes. The argument has been posited that a great presidency requires a great crisis or challenge, and the historian Toynebee (1961) hypothesized that great challenges met with creative responses provided ideal conditions for civilizations to flourish. A similar thread is found within successful projects of ATP and, one could argue, scientific advances throughout history. Great technical challenges require a greater and more innovative level of response. These technical and scientific challenges reflect the need for organizations to stretch beyond their typical level of comfort, embrace higher levels of ambitiousness, and push the boundaries of the technological frontier. The responses to these challenges often manifest themselves through greater and diverse collaboration or higher levels of commitment to project success. Projects and efforts that do not push the envelope may result in more individualistic attempts or tepid commitment since failing to achieve the full results does not represent a great loss to the scientific community. One study that examines one facet of this is a report on the effect of university participation on ATP projects. The report found that university involvement tend to be in areas involving "new" science and therefore the projects may experience more difficulty and delay but also are more likely to end successfully (Hall et al. 2002).

A second, and related result, is that successful projects that tackle significant problems require a dedicated and energetic champion for the technology. Great technical challenges often have someone or a group of people who are at the forefront of advocating new research and are committed to solving the problem. It is easier for a champion to remain committed to a project in the face of R&D obstacles when the stakes of failure appear high. This is true for all projects funded by ATP over its history. Project management history of ATP suggests that those projects with committed leaders often have better outcomes. A special study of sustainable collaborations conducted by Penn State supported this finding for research joint ventures as well (Petrick et al. 2006). While this finding suggests that public policy will want to tap into these committed champions, the problem of detecting and quantifying the commitment of project champions a priori remains a difficulty.

A third consistent result across all survey efforts was that single company projects and leads of joint ventures have similar outcomes while other joint venture members generally have lower levels of success. At the project level, joint ventures perform at least as well as single company projects but the measures of success are not spread equally across JV members. With joint ventures there appears to be little difference in performance across various types of joint ventures, e.g. the number of organizations, the existence of competitors, etc. The most obvious explanation of this is that the JV structure has been "pre-optimized" prior to applying for funding. For example, one might correctly assume that joint ventures with a large number of participants will face communication and coordination problems. Likewise, a JV with competitors present could find necessary levels of trust an impediment to success. The joint venture itself was aware of these problems as was the ATP evaluation board. In order for a JV to be funded, it had to demonstrate that the inherent difficulties in its structure have been considered and steps have been taken to mitigate these concerns. For example large JVs might have more regular meetings or have personnel from various members co-locate to reduce coordination problems (Dyer and Powell 2001 and Dyer et al. 2006).

From a public policy perspective, this funding shows that the benefits from the research do not flow equally to all partners in a joint venture. The joint venture lead may be critical in determining how quickly the benefits extend beyond the project.

The final consistent finding was that many of the important outcomes from R&D funding are quite intangible. When funding science, one can think of common measures of knowledge creation such as papers, presentations, and patents. But many results are reflected in increased human capital and learning, and direct measures of this are difficult to obtain. These outcomes are often best addressed through bibliometric analysis. From a public policy perspective, evaluation of innovation projects can be difficult. To determine impact may require a more long-term approach and a more creative assessment of outcomes.

2.4.1 BRS data

In addition to the common findings discussed above, there were several additional studies based on BRS data that produced findings regarding technology area and company size (Campbell et al. 2003 and Powell and Moris 2004):

- Projects in biotechnology are more likely to have journal publications and less likely to experience early revenues.
- Projects in information technology do not capture value through patenting and are more likely to experience early revenues.
- Small companies and large companies are about equally more likely to patent than mid-sized companies but large companies tend to have a larger average number of patents.
- Small companies are more likely to realize early revenues from the research but the levels of the revenue tend to be small (more work is needed to understand if these early revenues are a harbinger of future success or merely reflect financial pressures resulting in the need to commercialize before the technology is fully developed).
- Large companies (Fortune 500 or equivalent) are less likely to see revenues but, when they do, the amounts are substantial reflecting existing product lines and distribution chains.

Funding research on the cutting edge of technology meant that ATP was particularly interested in understanding the effects of university participation in ATP projects. Universities play a key role in the U.S. innovation system and are more often engaged in research at the scientific and technological frontier. Private companies may choose to collaborate with universities in order to gain access to eminent researchers, or knowledge that can enhance or complement their own. Universities may be motivated to participate in industry-university research collaborations to gain access to additional research funds or to direct their research toward solving industry problems. While the innovation process is non-linear with many feedback loops, for simplicity's sake it can be characterized as following a path from knowledge creation and dissemination to technology development to commercial application. Particular questions of interest for ATP included:

- Does university participation have an effect on R&D outputs?
- Does university participation indicate or reflect other, more general, characteristics of ATP projects?
- Does the type of university participation (e.g., as a subcontractor or joint venture partner) have an effect on R&D outputs?

Analysis of BRS data to address these questions as well as others can be summarized as follows:

- University participation has a positive effect on knowledge creation and dissemination, as measured by journal publications;
- University participation has a positive effect on research outputs (i.e., journal publications), which are early in the innovation timeline, but no discernable effect on later innovation outputs such as filed patents and early revenues;
- There are no discernable differences across technology fields in the effect of university participation on project outputs;
- Project structure and the functional role of universities in a project may be important factors in determining the effect of university participation on outputs;
- Projects with university participation are less likely to stop for adverse reasons, which may reflect essential differences in the motivation or characteristics of projects with university participation.

Measures of project outputs were derived from BRS data in a simple, conceptual timeline of the innovation process:

- knowledge creation (measured by journal publications and conference presentations);
- technology development (measured by patents filed and patents granted);
- and commercial application (measured by early revenues from products or services).

An additional output measure at the project level is project termination prior to completion of the project. Historically for ATP, just over 10% of projects stopped early for adverse reasons, including:

- change in company strategic goals, structure, markets, or other conditions;
- company financial distress;
- lack of technical progress on the project;
- change in project scope, membership, or other factors.

In interpreting these results and findings, it is important to keep in mind that project structure and university participation reflect characteristics of technology, industry, participants, etc. In other words, project structure and university participation are endogenous variables. Companies choose to collaborate with other companies, or to subcontract or partner with a university. Since this analysis examined what effect project structure and university participation have on project outputs, the dependent variable is outputs and the independent variable is project structure. In a broader analysis, project structure could be more formally modeled as the dependent variable in relation to other more fundamental determinants. These findings are with this broader context in mind.

2.4.2 Surveys of ATP Applicants data

ATP was unique as a program in systematically and comprehensively attempting to survey both non-awardees and awardees across funding competitions. The motivation for the surveys and the findings centered on the following analytic areas.

ATP was interested in the extent to which it was funding the "right" projects—those projects consistent with the published ATP selection criteria. Survey design incorporated operational measures of these criteria—namely innovativeness, high-risk, potential for broad-based benefits (spillovers) and the need for public funding. The overarching rationale for ATP is that to the extent that there is a misalignment of private and public interests for R&D activities, there is a systematic under-investment in R&D. The "wedge" between private and public interests occurs for several reasons: high technological risk, longer time horizons, the inability to capture a significant portion of the commercial benefits due to knowledge spillovers ("appropriability"), and higher coordination costs in overcoming riskier and more complex technical barriers. Analysis of project selection can help examine the extent to which ATP is funding projects that represent this wedge between private and public interests. Analysis of subsequent funding could address the extent to which ATP funding has made a difference in attracting the necessary resources to carry out the commercialization of the high-risk R&D.

Analysis was conducted for competitions in 2000, 2002, and 2004 (Kerwin and Campbell 2007; Survey of Applicant Factsheets 2003, 2005; Campbell and Wang 2004). Response rates for the three surveys were between about 50 and 75%. Analysis was done by Westat to check for systematic non-response bias across characteristics such as company size, technology area, single versus joint venture participation, and reviewer quality of the proposal. In all three surveys there was no evidence of non-response bias. The summary conclusions from the three Applicant Surveys are as follows:

- Projects with greater technical risk are more likely to receive an ATP award
- Projects with longer time horizons until commercialization are more likely to receive an ATP award
- Companies that receive an ATP award are subsequently able to attract and commit greater funding to the project line of research in the post-application period
- Depending on how a researcher categorizes indirect costs on an ATP project, ATP either crowds in additional investment or, at worst, crowds out a fraction of the private investment in the line or research (there is no evidence of complete crowding out of private investment)

ATP was also interested in examining its selection process. The selection process used both external peer review followed by deliberative discussion with an evaluation panel. Analysis was conducted to determine if there was any "value-add" from the selection panel above the initial peer reviews. There was consistent evidence that the selection panel assigned a premium to measures of risk and innovativeness (ex ante) and a premium to those projects that were less likely to continue doing any R&D in the proposed line of research (ex post).

One additional aspect of the Applicant Surveys was questions dealing with time and cost associated with proposal preparation and general customer satisfaction element regarding the fairness of the selection process. A large majority of ATP applicants thought the process in making the funding decision was a fair process and indicated another ATP "treatment effect," namely that there was value in proposal preparation independent of whether funding was received or not.

2.4.3 Survey of ATP Joint Ventures data

Innovation is an increasingly important dimension of competition in technology intensive industries. In seeking innovation, individual firms often find that external knowledge and research partners are critical to success. Therefore, firms increasingly enter into research and development (R&D) alliances with other firms to combine complementary knowledge in the pursuit of new innovative technologies. Indeed, many governments around the world support cooperative research activities in the expectation that collaborating firms will successfully develop new technologies that will improve economic competitiveness. Understanding how firms can enhance the probability of success in R&D alliances is an important question for both firms and governments. Researching the determinants of knowledge sharing and innovative success in R&D alliances is especially challenging since innovation processes are inherently uncertain.

To examine how alliance-design and alliance-management factors influence R&D alliance success, ATP made use of a unique survey dataset that includes 397 firms across 142 R&D joint ventures. These R&D joint ventures received funding from ATP. Analysis included examining alliance design factors that are expected to influence alliance success, such as the number of partners, type of partners (e.g., presence of competitors), and geographic proximity of partners. There was also consideration of firm-level attributes such as the firm's prior experience with alliances in general or with specific alliance partners, and the firm's existing stock of R&D knowledge and capabilities. These alliance design factors (alliance structure characteristics and firm-level attributes) are largely established at the time of alliance formation, and reflect the decisions made by the alliance designers (O'Brien et al. 2006).

The analysis also examined management factors that are expected to influence alliance success. Alliances that are able to establish effective governance arrangements and institute processes that build trust are expected to be more likely to share knowledge and achieve innovation success. Alliances that facilitate communication among partners effectively are also expected to be more likely to achieve innovation success. Alliance partner commitment and effort devoted to the alliance project, as measured by technical personnel resources allocated, is also expected to relate to alliance success. These alliance management factors develop during the course of the project, that is, in the process of alliance execution.

In addition to examining the relative importance of alliance design factors and alliance management factors in determining R&D alliance success, the program was interested in finding if partners in an R&D alliance realize similar, or dissimilar, benefits from participation in the alliance (Dyer et al. 2006).

The following conclusions were drawn from various empirical analyses:

- Number of alliance partners. The number of alliance partners has a weakly negative effect on patent application, and no effect on overall value or commercialization. The evidence suggests that alliance designers are largely successful in achieving an "optimal" number of alliance partners, balancing the marginal benefit of adding an additional partner to the marginal cost associated with an additional partner
- Presence of competitors. Simple correlations show that alliances with competitor firms have less frequent communication and lower levels of goodwill trust. But multiple regression analysis finds that the presence of competitors in an alliance has no effect on alliance outcomes. Again, this suggests that alliance designers are largely successful in "optimizing" the structure of the alliance.
- Geographic distance between alliance partners. Simple correlations show that alliances with greater geographic distance between partners have less joint work interaction, and lower levels of governance effectiveness and goodwill trust. But in multiple regression analysis, geographic distance has no effect on alliance outcomes.
- General and partner-specific alliance experience. General alliance experience and partner-specific experience have a negative effect on patent application as a performance outcome. This may suggest that creativity and invention are more likely when new partners come together in new collaborations to combine ideas, different approaches, and complementary knowledge.
- Number of technical personnel. The number of technical personnel resources has a positive effect on patent application and on commercialization of technology. This

result supports the view that innovation and learning outcomes depend on the number of technical personnel engaged in the effort.

- Frequency of communication. Frequency of communication has a strong statistically significant positive effect on all three outcomes measures for R&D alliance performance. (The three outcome measures are the overall assessment of the success of the alliance to deliver value to the company, patenting, and commercialization). The finding suggests that alliance managers can increase the likelihood of alliance success by establishing routines that encourage frequent communication. Frequent communication facilitates the knowledge sharing and coordination that is critical to alliance success.
- Goodwill trust. Measures of goodwill trust among alliance partners have a weakly negative effect on the perceptual measure of overall value, and a negative effect on the patent application measure. The results suggest that successful alliances do not depend only on goodwill trust, but develop contractual-based trust that is generated through contractual provisions and effective governance arrangements. In other words, in alliance management, one would do well to "Trust, but verify."

As was a previous consistent finding across all data collection efforts, "reaching for the stars" is a strong predictor of alliance success. More ambitious projects with farther reaching goals demonstrate greater success on all three measures of R&D alliance performance. More ambitious projects have intrinsically greater potential value and potential impact. In addition, more ambitious projects are likely to mobilize greater commitment and effort on the part of both the partner companies and the individual participants.

3 Developing a community of practice—a Data Enclave

Though ATP developed a strong series of surveys to study the innovation and technology development within the program, there were few internal resources available to conduct in-depth analyses of the collected data. Once ATP ended, it became critically important to make the data available to researchers and policy analysts. This was also important for the new Technology Innovation Program, as many of the results from ATP are still applicable for TIP.

The challenge for ATP was to establish a new approach that solved a series of technical and social challenges, namely:

1. The information is protected from access and use by unauthorized individuals and for unauthorized purposes.
2. Researchers are provided with a research environment that facilitates high quality research.
3. The benefits of researcher access to microdata are clearly demonstrated to justify both the risk and the cost of providing that access.[3]

As a result, ATP funded the National Opinion Research Center (NORC) to create a Data Enclave to provide remote or on-site researcher access to confidential microdata in a manner that fulfills each of these requirements (Lane and Shipp 2007). The Data Enclave[4]

[3] The United Nations (2007) prepared a publication *Managing Statistical Confidentiality & Microdata Access Principles and Guidelines of Good Practice* that describes core principles for researcher access to microdata. The publication also presents twenty case studies that demonstrate that there are a variety of ways to do this. Remote access to microdata is described for Australia, Canada, and Denmark.

[4] Data Enclave, go to: http://www.norc.org/DataEnclave/Datasets/NIST-TIP/.

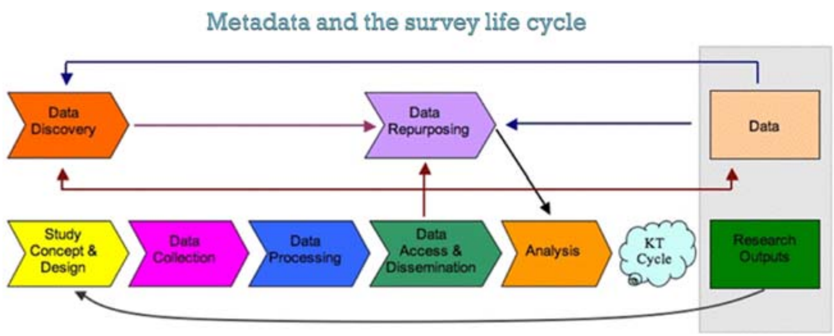

Fig. 1 Metadata and the survey life cycle (Humphrey and Hamilton 2004)

combines elements from the computing and social sciences to develop secure remote data access protocols. The protocols include high-level technical security that has been certified by NIST, as well as by other federal agencies for which NORC collects data such as the Bureau of Labor Statistics, the National Science Foundation, the Internal Revenue Service, and the Department of Health and Human Services. Other protocols include:

- a review process and legal agreements to ensure that only authorized researchers from approved institutions access data;
- audit logs and audit trails to monitor research behavior during data access; and
- full disclosure review of statistical results before they are permitted to leave the secure environment.

NORC, together with the data custodian, provides on-site training of researchers so that they are trained in confidentiality protection, as well as about the details of the dataset. NORC recognizes that each agency, and indeed each study, has different requirements and uses a portfolio approach to customize the access protocols to each agency's needs.

Researchers are provided with a research environment that facilitates documentation. This environment, or collaboratory, features wikis, blogs as well as direct interaction with data producers. The collaboratory enables researchers in different places to share files and to communicate information via blogs and wikis. This helps them capture the research process, compare results and communicate with data producers about different aspects of the data. The data documentation has been set up to be as user friendly as possible, using Data Documentation Initiative standards. Thus the environment not only promotes high quality research, but also promotes the interaction between producers and researchers that creates the healthy survey lifecycle. Humphrey and Hamilton (2004), of the University of Alberta, describe the importance of metadata in leveraging the value added of microdata. They conceptualize this lifecycle in Fig. 1. The Data Enclave's approach to metadata documentation has been set up to maximize the gains to researchers and to facilitate publication of results and increase visibility of their work. It is also designed to integrate research results into survey knowledge and to facilitate reporting and citation generation.

As a condition of access, the researchers are required to demonstrate that they are serving the agency mission. Researcher analyses of the data provide important findings to agencies that can be used to inform program operations and program outputs. Researchers can meet this requirement by providing detailed metadata documentation to enhance the database infrastructure, adding information or data to the survey, or providing their code to the agency and subsequent researchers. All researchers are required to also provide their research output for dissemination by the agency (although this does not preclude publication in journals), as well as evaluation and feedback of the survey.

The NORC Data Enclave is a successful approach for allowing researchers to remotely and securely access business and other confidential data. To initiate the use of the Data Enclave, the ATP program provided funds to researchers to undertake research projects that will inform the new Technology Innovation Program.[5]

4 Conclusions

As researchers and program developers call for greater collection and analysis of data on the impact of public policy on innovation, the ATP data represents a long-term effort to collect unique and robust data on the innovation process. ATP provides an exceptional source of data that researchers can use to test hypotheses about the innovation process within and across firms. The ATP data are also a useful source to examine the feasibility for constructing innovation metrics for the US as a whole. ATP data can inform public policy; for example, it can be used to address questions such as:

- What is the role of strategic alliances in enhancing innovation? What role do universities play in this process?
- How do startups spur innovation?
- What is the impact of government funding on the innovation process?
- What barriers do companies face when undertaking high-risk projects that lead to innovation?
- What are characteristics of companies who innovate?

To examine these questions and others, researchers can now access ATP data (as well as other data sources) through the NORC Data Enclave.

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[5] NORC Data Enclave Newsletter, Volume I, issues 3 and 4, July 2008, http://www.norc.org/NR/rdonlyres/81CDE8EB-438E-4689-A2BB-D2D7211C8E49/0/Newsletter34.pdf.

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